This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

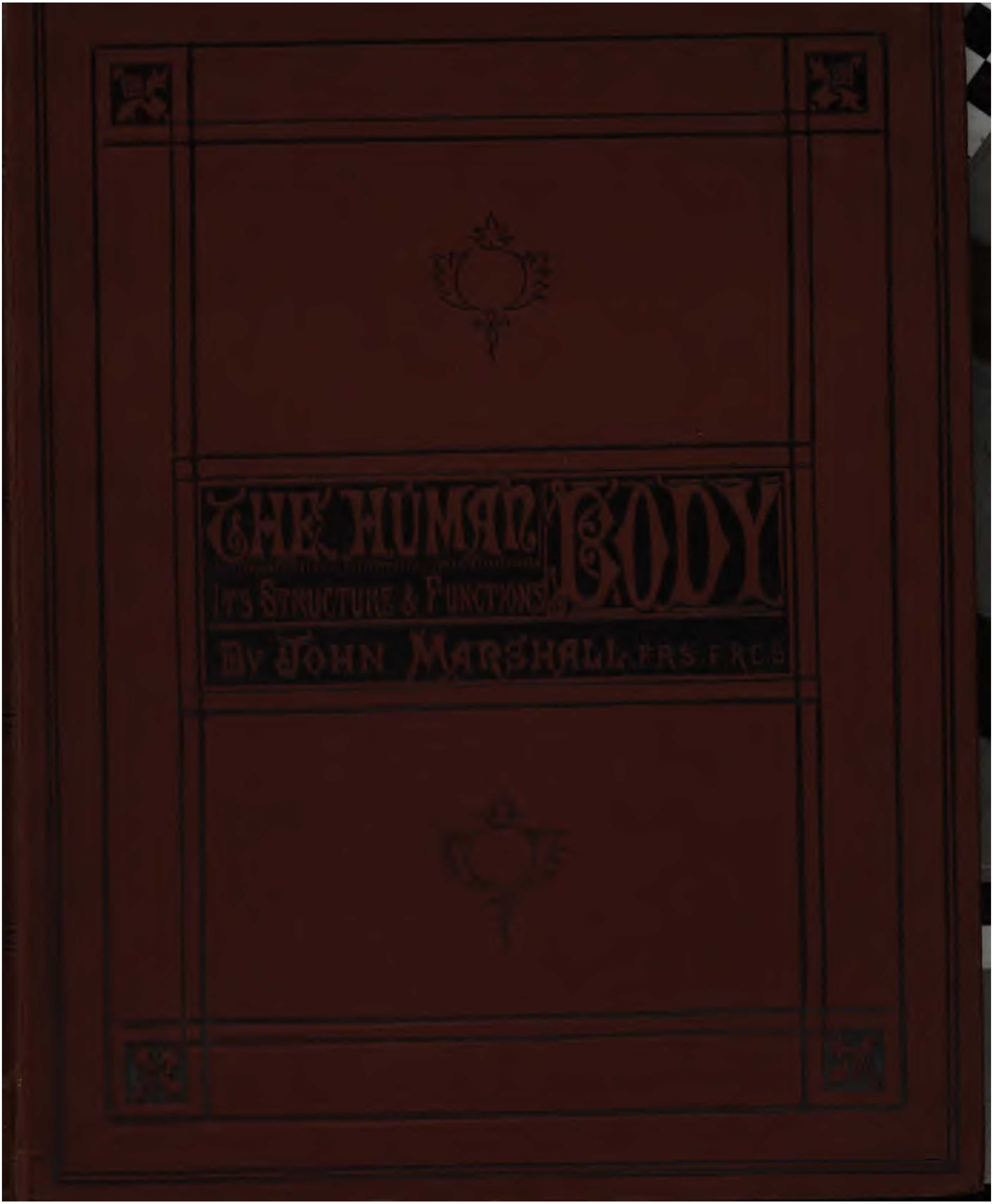
+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`



THE HUMAN BODY

ITS STRUCTURE & FUNCTIONS

BY JOHN MARSHALL, F.R.S. F.R.C.S.

A DESCRIPTION

OF

THE HUMAN BODY:

ITS STRUCTURE & FUNCTIONS.

ILLUSTRATED BY

NINE PHYSIOLOGICAL DIAGRAMS,

CONTAINING 193 COLOURED FIGURES,

DESIGNED FOR THE USE OF TEACHING IN SCHOOLS, AND YOUNG MEN DESTINED FOR THE MEDICAL PROFESSION, AND FOR POPULAR INSTRUCTION GENERALLY.

BY

JOHN MARSHALL, F.R.S., F.R.C.S.,

PROFESSOR OF SURGERY, UNIVERSITY COLLEGE, AND SURGEON TO THE UNIVERSITY COLLEGE HOSPITAL.

SECOND EDITION.

IN TWO VOLUMES.

VOLUME I.—TEXT.

LONDON:
PUBLISHED BY ALFRED TARRANT,
11, SEARLE STREET, LINCOLN'S-INN FIELDS.

1870.

[The Right of Translation is reserved by the Author.]

165. h. 13.

PREFACE.

THE first edition of this work having been exhausted, it has been resolved to reprint it.

The publication of the set of Large "Physiological Diagrams" herein described, was undertaken at the request of the Government Department of Science and Art, in order to place within reach of the Public, and especially of Teachers in non-Medical Colleges and Schools, appropriate and convenient materials to assist in communicating a general knowledge of the formation and uses of the different parts of the Human Body.

In the preparation of such a work, advantage was freely taken of existing anatomical plates of suitable character and good authority. The fullest acknowledgment of all such important aids is here offered.

From the excellent folio lithographs of MM. Bourgery and Jacob, published in Paris, 1821-9, the central figures in the Diagrams 1, 2, 3, 4, 5, and 7, have been chiefly derived; but in all cases details have been omitted, suitable modifications have been made, and the designs of M. Jacob have been utilized rather than copied. In Diagram 7, assistance has been derived from well-known plates published by Cruveilhier and Manec.

As to the numerous detached figures in all the above-named Diagrams, as well as the copious illustrations in Diagrams 6, 8, and 9,—together numbering 189 separate subjects,—it must suffice, in a popular work like the present, to state that most of them have been selected from sources which will easily be recognized by anatomists. Some, however, are original.

The drawings were prepared by Mr. John S. Cuthbert, and Zincographed by Messrs. Day and Son.

The following account of the structure of the body, will, it is believed, fully supply all the wants of the non-Medical teacher of Anatomy. Subjects which could not with propriety be introduced into general instruction, have been entirely avoided. On the other hand, the Organs of the Senses, which are especially suited for popular demonstration, are rather more fully treated of than other parts.

Accompanying this volume are nine tinted Lithographic Plates, which, being facsimile reductions of the Large Diagrams, will be found of great convenience to Teachers, for consultation and for illustrating the text, when the larger figures are not at hand. They also render the following description complete, as an independent book for general use.

CONTENTS.

INTRODUCTION .... *Page* ix

1. THE SKELETON AND LIGAMENTS 1

2. THE MUSCLES, JOINTS, AND ANIMAL MECHANICS 17

3. THE VISCERA IN POSITION. THE STRUCTURE OF THE LUNGS 28

4. THE HEART AND BLOOD-VESSELS 50

5. THE LYMPHATICS, OR ABSORBENTS 73

6. THE DIGESTIVE ORGANS 81

7. THE BRAIN AND NERVES. THE ORGAN OF VOICE 111

8. THE ORGANS OF THE SENSES 156

9. THE MICROSCOPIC ANATOMY OF THE TEXTURES 227

INTRODUCTION.

The Human body, like that of animals generally, is composed of many different *parts*, serving different *uses* or *offices* in the living economy. These are called *Organs*, from a Greek word ὀργανον, organon, an *instrument;* and their several actions are named *Functions*. Thus the *eyes* are the *organs of sight*, and the *lungs* the *organs of breathing;* whilst *sight* and *breathing* are the functions of those parts.

Plants, too, have their organs; and hence animals and vegetables are said to have an *organic* structure, or to be *organized*, and to belong to the *Organic* kingdom of nature, as distinguished from mineral substances, which belong to the *Inorganic* kingdom.

Anatomy teaches us the structure of organs, whilst Physiology explains their functions; and in order to facilitate their systematic study and description, it is usual to classify them into sets or groups, harmonizing with certain offices which they serve in common.

There are in the animal economy two great divisions of these organs, viz. the *Organs of Animal life* and the *Organs of Vegetative life.*

The organs of *animal life* consist, first, of the *organs of support*, *locomotion*, and *prehension*, which include the bones, joints, and muscles, and those parts of the nervous system which control them; and, secondly, of the *organs of sensation*, *emotion*, *intellect*, and *will*, namely, the *organs of the senses*, the skin, tongue, palate, nose, ears, and eyes, with the sensitive parts of the *nervous system* associated with sensation, and with the higher mental functions. The organs of animal life, so named because they are possessed by animals only, are also termed the *organs of relation* or of *relative life*, because they serve to establish special relations with the external world. Their functions are called the *animal functions*.

The organs of *vegetative life*, so named because they are common to plants and animals, are the *organs of digestion*, *absorption*, *circulation*, *respiration*, *secretion*, *excretion*, and *reproduction*. The functions of these organs are called the *vegetative functions*, and also the *nutritive* and *reproductive functions*, as they are concerned in the nourishment of the body and the continuation of the species.

The various organs, as is found on dissection, are themselves constructed of dissimilar parts, which again are composed of a certain number of structures called *Tissues* or *Textures*, made up of numerous similar microscopic constituent elements. Thus the tongue consists chiefly of a *fleshy* basis, covered in by an expanded *membrane* provided with parts called *glands*, the whole being supplied with *blood-vessels* and *blood*, with *absorbent vessels* and *lymph*, and with *nerves*. Now, each of these parts may be again resolved into textures composed of aggregations of similar microscopic particles, *fibrous*, *tubular*, or *vesicular*, constituting the *connective*, *elastic*, *muscular*, *nervous*, *vascular*, and *epithelial* tissues.

Descriptive Anatomy gives an account of the Organs, and General Anatomy or Histology (ἱστος, histos, a *web*, and λογος, logos, a *discourse*) of the Textures.

The order of description adopted in the following pages is typographical rather than systematic, and is not without its conveniences. But the Teacher may study or lecture upon them on any method, and in various modes of combination. The Animal organs are illustrated in Diagrams 1, 2, 7, and 8; and the Vegetative organs, in a natural order, in Diagrams 6, 5, 4, and 3. The Textures are fully illustrated in Diagram 9, which may be examined before or after, or in conjunction with any of the others.

The Teacher is further recommended to obtain from dead animals, whenever possible, the corresponding organs or textures, as an additional means of illustrating the descriptions, and conveying information to his class.

The skeleton, the joints, the muscles or flesh, the general position of the several organs within the body, nay, even the general character and structure of those organs, which, in spite of many differences, are common to man and animals, may be well illustrated on the dead body of the rabbit or of the hare, which is usually less fat. The skeleton of one of those animals, or of a dog, prepared by allowing the flesh to decay away or putrify in water for a few weeks in warm weather, and occasionally brushing it away from the bones so as to leave the ligaments which tie the bones together at the joints, will be found very useful. The brain, the nasal cavities, the internal ear, the orbit and eye, the parts in the mouth and throat, the larynx, windpipe, and lungs, may be conveniently obtained from the sheep; whilst the heart is better examined in the calf or ox; and so also, on account of its superior size, is the eyeball. The eye of a white rabbit, or any other albino animal, is well suited, from its transparency, to show the image formed at the back of the eyeball. The pigeon, the common snake, the frog, and the haddock or cod, will exemplify the organs of the bird, the reptile, the batrachian, and the fish. The textures may nearly all be prepared for microscopical examination, from the tongue and larynx of the sheep.

A DESCRIPTION OF

THE HUMAN BODY.

ILLUSTRATED BY NINE PHYSIOLOGICAL DIAGRAMS.

No. 1.—The Skeleton and Ligaments.

◆

This diagram illustrates the *Osseous System*,—that is, the bony framework, internal *Skeleton*, or *Bones* of the human body. It also shows the mode in which the natural skeleton is held together at the *Joints*.

The central figure (fig. 1) represents the skeleton seen in front, as if in a standing posture. The shaded outline of the human form serves to indicate the thickness of the soft parts covering the bones during life, and also the position of the latter within the former.

Nearly all the individual osseous pieces or bones are here seen; but the spine, the shoulder-bones, and some of the bones of the head, are only partially displayed. One small bone, called the *Hyoid bone*, situated in front of the neck, below the tongue (see diagram No. 6, fig. 3, h), is omitted for the sake of clearness.

On the right side of the skeleton,—that is, to the left of the spectator,—the separate bones are shown as if put together in their natural positions one upon the other. They are tinted yellow; but in some instances their ends, which are partly visible, as in the right arm-bone M, are represented as if covered with a layer of a bluish-white substance, named *Cartilage* or *Gristle*.

On the left side of the figure the bones are represented held together at the joints, as at the knee, elbow, hip, &c., by strong bands or membranes called *Ligaments*, which are coloured grayish white.

The smaller figures (figs. 2 to 16) afford additional illustrations of certain parts of the skeleton. In them, also, bone is distinguished by a yellow, and cartilage by a bluish tint.

The Italic capital letters referring to the bones correspond in all the figures. The ligaments in the central figure are marked by small Roman characters.

So much depends, even for the purposes of popular knowledge, on a clear insight into the structure of the skeleton, that this diagram is very fully described. By carefully studying the following account, the names of all the bones will be acquired, whilst, at the same time, through the eye, their individual forms, their position in the skeleton, and also the great subdivisions of the latter, will be recognized and remembered.

But the utility of this diagram extends to other purposes.

First, it will serve in explaining the many uses of the skeleton; showing how it determines the general form, the height, width, and proportions of the body; how it supports the soft parts and protects important organs, forming cavities in the skull and spine for the brain and spinal cord, in the face for the organs of the senses, and in the chest for the heart and lungs; and further, how every part of the bony framework is contrived under the dominant idea of fitness for the erect attitude, as seen in the balance of the head on the neck, in the curves of the spine, and its increasing strength from the neck to the loins; in the width of the hips and great strength of their bones; in the approximation of the knees, and the broad surfaces of those joints; in the vertical legs, the simple ancle-joints, and the arched form of the human feet: and lastly, in the special adaptation of the upper limb, not for locomotion, but for free prehensile movements and exquisite dexterity and tact.

Secondly, this diagram must be used in conjunction with others, to explain the mechanism of certain functions of the human frame, in which muscular movement takes a part: as, for example, *locomotion*, *prehension*, *mastication*, and *respiration*. The lever-like office of the several pieces of the skeleton, the shaping and fitting together of these at the joints, the mode in which they are held together, the positions of the fulcra in these joints or on some external point of support, and the broad surfaces or jutting processes of bone for the attachment of the muscles or sources of power, can all be demonstrated by aid of this and No. 2 diagram. The explanation of the mechanism of breathing requires reference to this diagram, as well as to diagram No. 3, and so on.

Thirdly, it shows that the skeleton of man, as well as that of fishes, batrachians, reptiles, birds, and the mammalia generally, presents a central part or axis, consisting of a series of bony segments called *vertebræ*, and named the *vertebral column*. This is a characteristic mark of the vertebrate type of animal creation, at the head of which, though far above the creatures next below us, stands our own species.

In teaching from this diagram, it must be borne in mind, that during life, and in the midst of the living tissues, the bones are not dry, hollow, naked, yellow, dead, and unchangeable things; but, though hard, are moist, pinkish, living structures, filled with marrow, covered by a firm membrane, named the *periosteum*, provided with proper blood-vessels and nerves, and subjected to incessant vital changes connected with their nutrition.

When stripped of their periosteum and sawn through (diagram No. 2, figs. 5, 7, and 8), the bones generally are seen to be composed of a dense layer outside, called the compact bony tissue, and of a more open or porous texture inside, named the spongy texture. In the open spaces or cells of this spongy tissue are found the marrow, the blood-vessels, and nerves. The small holes seen on the surfaces of the bones are for the passage of blood-vessels and nerves to their interior. The microscopic structure is fully explained under diagram No. 9, figs. 25, 26, 27.

The bones take three general forms to suit different purposes: thus they are—*broad*, as in the head and hip-bones; *short*, as in the spine, wrist, and ankle; *long*, as in the case of the ribs and most of the bones in the limbs. Omitting the patellæ and sesamoid bones, and counting the sacrum, the coccyx, the sternum, and the hyoid bone each as single bones, there are 198 bones in the entire skeleton.

THE BONES.

Figure 1.

The entire skeleton here represented may be divided into a central part, corresponding with the *Head* and *Trunk;* and of lateral or appended parts, called the *Limbs.*

THE HEAD.

The Bones of the Head are shown in figs. 2 and 3, as well as in the central fig. 1, being marked in each with corresponding letters.

The Head comprises the *Cranium*, or *Skull* proper, and the *Face*,—the plane of junction of these two parts being indicated by a line drawn from the root of the nose, G, fig. 2, backwards through the opening for the ear, J.

The Cranium.

The Cranium is the comparatively smooth hollow part of the head. It consists of eight bones, named and marked as follows:—one *frontal*, A; two *parietal*, B; two *temporal*, C; one *occipital*, H; one *sphenoid*, and one *ethmoid.*

The two latter are placed at the base of the Cranium, and though not lettered, are referred to further on, and also in the description of figs. 2 and 3.

The Cranium contains and protects the brain, or great centre of the nervous system. The deep and most essential parts of the organs of hearing are also lodged in the substance of two of the cranial bones; viz. the temporal bones.

The Face.

The Face, which is more uneven than the Cranium, includes cavities for the organs of sight, smell, and taste; viz., the orbits or eye-sockets, G, the nose-cavities, and the mouth.

It contains fourteen bones;—two *malar* or *cheek* bones, D; two *superior maxillary* or *upper jaw-bones*, E; one *lower jaw-bone* or *inferior maxillary* bone, F; two *nasal* or *nose* bones, I; two *lacrymal* bones; one *vomer* or *ploughshare*-bone; two *turbinated* bones, and two *palate*-bones.

The three last named, though not lettered, are referred to under figs. 2 and 3.

The lacrymal bones and the vomer will also be again mentioned presently.

The different pieces or bones of the cranium fit closely together at their edges, which, being in some places smooth, but in others jagged, form at their places of meeting certain lines called *sutures*, which are sometimes plain and sometimes zigzag. The lines of junction of the facial bones are also called sutures: they are for the most part plain, and not toothed like the cranial sutures.

We may now separately examine the three views of the Bones of the Head given in this diagram; and, first, of the three-quarter view in fig. 1.

The Cranium.

A.—*Frontal bone*, forming the forehead, and the roofs of both orbits, or eye-sockets.

B.—Right *Parietal bone*, forming, with its fellow, the vault, vertex, or crown of the cranium, and a large part of its sides.

C.—Right *Temporal bone*, corresponding with the right temple,—again and more particularly noticed under figs. 2 and 3.

The Face.

D.—Right *Malar bone*, or cheek-bone, which forms the prominence of the cheek, assists also in completing the orbit, and helps to ward off blows from the eyeball.

E.—Right *Superior Maxillary bone*, forming half of the *upper jaw*. The bones of the two sides enter into the orbits, form the sides and chief part of the floor of the cavities of the nose, and the greater part of the roof of the mouth. They contain sockets for the sixteen upper teeth.

F.—*Lower jaw*, a single bone, which completes the face below, forms the chin, and is furnished with sockets for the sixteen lower teeth.

G.—Left *orbit*, or *eye-socket*. These deep cavities are situated between the cranium and the face; no less than seven bones enter into the formation of each, but three of these are common to both cavities. The optic nerve, or nerve of sight, enters the orbit behind, at the very bottom of the socket. Besides this nerve, several other nerves, the eyeball and its numerous muscles and vessels, each orbit lodges, at its upper and outer corner, a gland, called the *lacrymal* gland, which secretes the tears. On the inner wall of each orbit, near the nose, is a small delicate bone, called the *lacrymal bone*, which, together with a part of the upper jaw-bone, forms a canal, named the *lacrymal canal*. This gives passage to a membranous sac and duct, intended to convey the superfluous moisture of the tears down into the nasal cavity. Three small holes—seen one above the orbit, one below it, and one in the lower jaw—transmit branches of the fifth cranial nerve, which are sensory nerves distributed to the face. (See also fig. 2.)

I.—Right and left *Nasal bones*, forming the bridge of the nose. The large opening beneath these leads into the right and left cavities of the nose, which are separated from one another by a bony partition in the middle line, formed above and in front by a piece of the *ethmoid* bone, and behind and below by the *vomer* or ploughshare-bone.

Figure 2.

This figure shows the left side of the Bones of the Head, including the Cranium and the Face.

A.—Left *Frontal bone*, forming the forehead.

B.—Left *Parietal bone*, forming the crown and side of the head.

C.—Left *Temporal bone*, which contains the deep parts of the organ of hearing. J is the opening leading to those parts of the ear. The flat part of the bone above J is the *squamous* portion of the temporal bone; the part projecting down behind it is the *mastoid* portion; the opening itself is in the *petrous* or hard portion, which is further shown in the base of the cranium (fig. 3). In front of the ear-opening, J, is a narrow process called the *zygoma*, which joins the malar bone, D, to form the *zygomatic arch*. The large depression above the zygoma is the *temporal fossa*, which extends upwards upon the frontal and parietal bones as high as the semicircular line on the side of the cranium, and during life is occupied by a muscle called the *temporal*. A small piece of the sphenoid bone appears near the fore-part of the temporal fossa.

D.—Left *Malar* or *Cheek bone*.

E.—Left *Superior Maxillary bone*, containing its eight teeth.

F.—Left half of *Lower Jaw-bone*, or *Inferior Maxilla*, containing also eight teeth. The back part of this bone turns up behind, and ends in a smooth eminence called the *condyle*, which forms a joint with a shallow socket in the temporal bone, placed close in front of the ear-opening, J. In front of this joint, a part of the lower jaw projects up into the temporal fossa, under cover of the zygoma, and forms a lever for the attachment of the temporal muscle just mentioned, which in contracting draws the lower jaw upwards, as in biting.

G.—Left Eye-socket or Orbit. Its outer border is here seen to fall back, as compared with the inner one, and thus allows of an increased lateral range of vision. The little *lacrymal bone*, and the upper part of the *lacrymal* canal, already mentioned in fig. 1, are seen on the inner wall of the orbit.

H.—Left half of *Occipital bone*. This bone forms the back part of the head or *Occiput*, and also a large part of the base of the cranium, reaching so far forwards as to form the roof of the throat. It is by this bone that the head is joined to the neck. (See also fig. 3.)

I.—Left *Nasal bone*. The deep notch below this bone, opposite to D, is filled up during life by the cartilages, or gristly part of the nose.

J.—External Auditory Opening leading to the deep parts of the ear.

Figure 3.

A section of the Bones of the Head, made by sawing a little to the left of the middle line, and showing the inner surface of the left half of the cranium and face. Many facts are here represented;—such as the hollowness of the cranium, the proportionate thickness of its walls, the comparative evenness of the interior of the vault and sides of the cranium, the irregularity of its base, the sutures and the grooves for blood-vessels on its inner surface. The cavities of the nose and mouth are also seen. The cut edge of the cranial bones shows them to consist of an outer and inner compact layer of bone, called the *tables* of the skull, with an open or porous tissue, named the *diploe*, between them.

A.—Left half of *Frontal bone*. Corresponding with the projecting lower part of the forehead is a cavity in the bone, formed by the separation of its outer and inner compact layers or tables: it is called the *frontal sinus*, and communicates with the cavity of the nose.

B.—Left *Parietal bone*.

C.—Left *Temporal bone,*—its petrous portion, which projects into the base of the cranium, and contains the essential part of the organ of hearing. The opening for the left nerve of hearing, or auditory nerve, is seen upon it.

H.—Left half of *Occipital bone,* forming the back of the head, and reaching forwards in the base of the cranium to the back of the throat. Opposite H is the *occipital protuberance,* which is thick, and strengthens that part against blows. Above the letter C, the cut edges of the bone are interrupted, for here the saw has passed across a large opening, called the *foramen magnum,* through which, during life, the spinal cord descends from the brain into a canal formed within the back-bones or spine. The line from the letter C to the temporal bone passes through this opening. In front of this line on the left margin of the opening, is a smooth projection, called a *condyle* (the right margin here cut away also has its condyle): these two condyles are received into corresponding smooth hollows in the upper surface of the first cervical vertebra, shown in fig. 5; and so the head is jointed to the neck. (See also diagram No. 7, fig. 5.)

At the back of the throat, the occipital bone is blended with the central part of the *sphenoid bone,* recognizable in the figure by the large hollows or sinuses in it. Between these sphenoidal sinuses and the frontal sinus, the base of the cranium is completed by the *ethmoid bone,* the left half of which is shown, where it assists to form the side of the left nasal cavity, to be perforated and channelled for branches of the left olfactory nerve, or nerve of smell. Below the channelled part is the middle turbinated or twisted bone, also a portion of the *ethmoid.* Below this is an independent bone, named specially the *Turbinated bone.* It is the outer wall of the left cavity of the nose which is here seen; the median partition (seen in front in fig. 1), which separates it from the right cavity, is cut away. Both nasal cavities open into the throat, behind the roof of the mouth, or *palate.* The bony palate is formed in front by a part of the upper jaw-bones, but to a small extent behind by the proper *palate-bones.*

E.—Left *Superior Maxillary bone*;—here seen to form the left half of the upper jaw, part of the side and floor of the left nasal cavity, and also of the roof of the mouth, or hard palate.

F.—Left half of *Lower Jaw-bone,* cut through at the chin.

I.—Left *Nasal bone,*—the inner surface, forming part of the side and roof of the left nasal cavity.

THE TRUNK.

Figure 1 *(resumed).*

The *Trunk* comprises the *Back-bone* or *Spine,* the *Ribs* and the *Breast-bone,* the *Shoulder* and *Collar-bones,* and the *Hip bones.*

The Spine.

The Spine is the median column of the skeleton, which reaches from the base of the skull to the lower end of the trunk. It consists of many small bones, which are called *vertebræ.* The whole column is named the *Vertebral* or *Spinal Column.*

The upper part of the Spine is the *neck,* or *cervical portion,* V. c. 7, which contains seven vertebræ; then comes the *back* or *dorsal part*, V. d. 1 to 12, consisting of twelve vertebræ; next, the *loins* or *lumbar* portion, V. l. 5, composed of five vertebræ. Below this is the *sacrum*, or *sacral part*, S, in which five vertebræ may be traced; and lastly, the *coccyx*, *tail*, or *coccygeal part*, which contains four pieces. In all there are thirty-three vertebræ.

The following special references will assist in the study of these bones.

V. c. 7.—The four lowermost of the seven *cervical vertebræ;* the others are hidden by the face.

V. d. 1.—First *dorsal vertebra.*

V. d. 12.—Twelfth, or last, *dorsal vertebra.*

The second, third, and eleventh dorsal vertebræ are also partly seen; but the rest are concealed from view by the breast-bone, which is marked with an asterisk. The dorsal vertebræ are distinguished by supporting the ribs on each side.

V. l. 5.—The five *lumbar vertebræ*, or bones of the loins.

The vertebræ of the neck, back, and loins, together twenty-four in number, are called movable vertebræ. Their bodies—that is, the thick parts turned forwards, and seen in the figure—are strongly connected together by thick pads of fibro-cartilaginous substance: these are the *intervertebral substances*, the edges of which, coloured bluish, are visible between the vertebræ, as best displayed in the lumbar region.

The remaining vertebræ, sacral and coccygeal, have no intermediate soft pads, but are more or less blended together, and are called immovable.

S.—The *Sacrum*, made up originally of five vertebræ, which are afterwards united into one large wedge-shaped bone, is broad above to receive the last lumbar vertebra, and narrow below, where it is joined by the first of the coccygeal vertebræ, which form the *Coccyx*, only partially visible in the diagram.

A side view of a section down through the middle of the Head and Spine, given in fig. 5, diagram No. 7, shows all the vertebræ in connection, together with the intervertebral substances.

The entire spine is here seen to be curved, not straight—being convex forwards in the neck, backwards in the back, forwards again in the loins, and backwards at the sacrum and coccyx. This figure also shows the existence of a canal behind the bodies of the vertebræ, in which the spinal cord, a prolongation of the brain, is contained and protected. This is the *spinal canal.* Behind it are seen certain backward projections of the vertebræ, called the *spinous processes*, or *spines*, from which the entire column derives its name.

The vertebral column supports the head, upper limbs, and, of course, the body itself,—the sacrum receiving the weight transmitted through the lumbar vertebræ, and in its turn transmitting this to the hip-bones.

Figures 4 to 14.

These drawings illustrate the forms of particular vertebræ or bones of the spine.

Figs. 4 to 8 represent, under different aspects, the *first* and *second cervical* vertebræ, which take a special share in the movements of the head upon the neck. Figures 9 and 10 are two views of an ordinary *cervical* vertebra; figures 11 and 12, of a characteristic *dorsal* vertebra; and figures 13 and 14, of a *lumbar* vertebra.

Fig. 4.—The first and second Cervical Vertebræ in their natural position, the one resting on the other as seen from behind. V. c. 1 is the first, and V. c. 2, the second vertebra.
Fig. 5.—The first Cervical Vertebra, also called the *Atlas*, seen from above, the fore-part being turned downwards.
Fig. 6.—The left side of the same bone.
Fig. 7.—The second Cervical Vertebra, specially named the *Axis*, seen from above, the front being turned downwards.
Fig. 8.—The left side of the same bone.

On studying these figures, it is seen that the first cervical vertebra forms a wide bony ring, on the upper surface of which, at the sides, are two ear-shaped hollow surfaces covered with cartilage. Into these the two condyles of the occipital bone are received and jointed, so that the head can be rocked backwards and forwards, as in looking up or nodding, upon the first vertebra of the neck. This vertebra is called the *Atlas*, because it immediately supports the head. When the head is turned or rotated from side to side, the atlas moves with it, and the joints then called into play are those between the atlas and the next vertebra. This, the second cervical vertebra, is more compact in form, and is thicker in front, where it has an upright process, like a tooth, which passes up into the fore-part of the ring of the atlas, and is kept in its place by ligaments. At the sides of this process are two flattish surfaces covered with cartilage, on which the atlas rests, and so carrying the occiput and entire head with it, rotates or turns partially round the *tooth-like process* of the second vertebra, which accordingly is named the *Axis*, or *Dentate Vertebra*.

Fig. 9.—The right side of an ordinary Cervical Vertebra,—say the fifth bone of the neck.
Fig. 10.—The same bone, seen from above,—the front being turned downwards.
A comparison of this bone with the atlas and axis shows how much the two upper cervical vertebræ are specially modified to suit their particular purposes.
Fig. 11.—The right side of a characteristic Dorsal Vertebra, from the middle of the back.
Fig. 12.—The same bone, seen from above, front downwards.
Fig. 13.—The right side of a Lumbar Vertebra, from the middle of the loins.
Fig. 14.—The same bone, seen from above, front downwards.

By examining this last series of figures, 9 to 14, the several parts of a movable vertebra may be learned, and also the modifications which they present in the neck, back, and loins.

The thick part, or *body*, turned forwards in the natural skeleton, and connected, as already mentioned, with the bodies of adjoining vertebræ by the *intervertebral substances*, gets gradually larger from neck to loins in proportion to the weight to be borne by it. In the back, the bodies of the vertebræ support the ribs, having little facettes for that purpose. The slender open part behind, named the *ring*, combines with the other rings to form the *spinal canal*, for the lodgment of the spinal cord and the roots of the spinal nerves: this is larger where its contents are more voluminous, or the movements of the spine are freer, as in the loins, and especially in the neck. The lateral projections, named *transverse processes*, and the backward projection, called the *spinous process*, are principally for the attachment of muscles. They are short and horizontal in the neck, so as not to impede movement; long—especially the spines which descend and overlap—in the back, where the movements are restricted; large and horizontal in the loins, to allow again of movement, and to afford attachment to the strong muscles which erect the spine. In the neck, the transverse processes are pierced by a hole, through which an artery ascends, and ultimately enters the cranium. In the back, the transverse processes are marked by small smooth surfaces, which touch the ribs. The two smooth bluish surfaces, tipped with cartilage, one on each side of the open part or ring, form joints above and below with the neighbouring vertebræ: they are horizontal, or oblique, and flat in the neck; vertical and flat in the back; vertical, but alternately concave and convex, in the loins. As seen in the side views, figs. 9, 11, and 13, there is, at the junction of the ring with the body, a *notch*, above and below: when approximated together in the spinal column, these notches form the *intervertebral holes*, or *foramina*, through which the spinal nerves pass out on each side from the spinal chord: the size of these holes corresponds with that of the nerves which pass through them.

It may be useful here to caution the reader, that in the modern language of Philosophical Anatomy,—one object of which is, by a close comparison of the skeletons of all the vertebrata, from fishes up to man, to determine the correspondences of the different bones, and thus to trace an ideal archetype in vertebrate organization,—the word Vertebra has a more extended signification than that assigned to it in the text, and in treatises upon Descriptive Anatomy generally.

In this wider sense, a Vertebra is one of a series of bony segments which, placed one behind the other from head to tail, constitute the *axis* of a vertebrate skeleton. In man, a good example of such a vertebral segment may be taken from the dorsal region, where a dorsal vertebra, in this fuller sense, includes the vertebra commonly so called, the two ribs which correspond to it on each side, the costal cartilages of those ribs, and the intermediate portion of the sternum; so that the perfect vertebra or vertebral segment consists of *a body* or *centrum*, and of *two rings* or *arches*,—one posterior, which surrounds the spinal chord or nervous centre, called the *neural arch*, and one anterior, named the *hæmal arch*, which encloses the vascular centre, or heart and great blood-vessels. The vertebral segments, higher up and lower down than the dorsal region, are variously modified, in ways which cannot be described here, either by changes in their form, loss of some of their component parts, or by displacements of those parts more or less altered in shape.

On this view, even the cranial and facial bones are looked on as extreme modifications of the parts of vertebral segments, called cranial vertebræ, of which there are said to be four, named occipital, parietal, frontal, and nasal: in the other direction, the last bone of the coccyx is likewise a distinct vertebral segment, reduced to its centrum or body only. The shoulder-bones, collar-bones, and hip-bones are also regarded as modifications of parts of the anterior arches of certain vertebral segments, to which the upper and lower limbs, which we have soon to examine, are said to be attached as special superadded parts or *appendages*.

Figure 1 (*resumed*).

The Ribs and Breast-bone.

The *Ribs*, or *Costæ*, are twenty-four in number, twelve on each side.

R. 1.—First *Rib* of the right side.

R. 12.—Twelfth, or last, *Rib* of the right side.

The intermediate ribs may be recognized by counting. The ribs are slender curved bones, which increase in length from the first to the eighth, and then become shorter to the twelfth. They are attached behind to the bodies and transverse processes of the dorsal vertabræ; in front they are continuous with certain gristly parts or cartilages (tinted bluish-white), named *Costal Cartilages.* These costal cartilages differ from the cartilages of the joints, and have a special significance in the skeleton, of which they may be said to be unossified parts. The seven upper ribs are connected by their cartilages to the Breast-bone, or Sternum, and are called *true* ribs; the five lower ones are called *false* ribs, because they are not so connected with the sternum. The eighth, ninth, and tenth costal cartilages are respectively connected with the one just above them; the eleventh and twelfth end free in the muscles, and are hence called *floating ribs.*

The *Sternum*, or *Breast-bone*, marked with an asterisk, thus *, is a flat bone, shaped somewhat like a short straight sword. It receives the cartilages of the seven upper or true ribs on each side, and the right and left collar-bones at its upper end. It consists of two pieces, the upper one being short, and corresponding to one rib and a half on each side. The lower end is tipped with a cartilage, called the *ensiform appendage*, easily felt at the pit of the stomach.

The Sternum, the twenty-four Ribs and their cartilages, and the twelve Dorsal Vertebræ form the framework of the spacious cavity named the *Chest* or *Thorax*, which, during life, lodges and protects, besides other smaller parts, the lungs, the heart and great blood-vessels, the œsophagus or gullet, and the thoracic duct. The cartilages of the ribs endow the thoracic walls with great elasticity and freedom of movement.

The Shoulder and Collar bones.

The *bones* meeting at the *shoulder*, two in number on each side, namely the *Collar-bone* and the *Spade-bone*, form the bases of support for the upper limbs.

K.—Right *Collar-bone*, or *Clavicle*, connected by a joint with the top of the breast-bone at its inner end, and having the spade-bone suspended to its outer end.

L.—Right *Spade-bone, Blade-bone*, or *Scapula*, situated in the back, behind the ribs, by which, in the diagram, it is partly concealed. It has no attachment by joints to any other bone than to the collar-bone, to which it is connected by two projecting parts, called the *acromion* and the *coracoid processes;* the former being felt at the point of the shoulder, and the latter being placed below the collar-bone. The top of the sternum *, on which the inner end of the collar-bone rests, is, therefore, the only fulcrum or point of solid support to the upper limb. A shallow cavity, named the *glenoid cavity*, is formed on the scapula, for the head of the arm-bone, M, to play in: it is protected by the acromion process above, and by the caracoid process on its inner side.

The Hip-bones.

The *Hip-bones*, one right and the other left, form, together with the sacrum, a fixed base of support for the lower limbs. They correspond with the shoulder and collar bones at the upper part of the trunk, but present a remarkable contrast to them in forming a fixed instead of a movable base of support to the attached limbs. Each hip-bone, also called the *Innominate*, or *unnamed* bone, is originally composed of three separate pieces, which, though ultimately blended into one broad and irregularly-shaped bone, continue to receive different names; as follow:—

U. 1.—Right *Iliac bone*, or *Ilium*, the broad part which supports the flank of the body.
U. 2.—Right *Pubic bone*, or *Pubes*, joined by ligaments to its fellow in the middle line.
U. 3.—Right *Ischium*, or *Sitting bone*, on which the weight of the body is supported in the sitting posture.

These three portions of the hip-bone meet and are consolidated into one bone at the deep socket, named the *Acetabulum*, which receives the head or upper end of the thigh-bone, W.

The right and left hip-bones join together in front to form the *pubic arch*. On each side of this is a large hole in the bone, called the *obturator foramen*, which, during life, is closed by a strong membrane; the object of which seems to be to gain lightness without any sacrifice of strength. The two hip-bones are most firmly attached behind to the sacrum, S, with which and the coccyx they thus form a very strong circle or hoop, called the *Pelvis*, or *basin*. Besides supporting the abdominal and protecting the pelvic viscera, the pelvis transmits the weight of the body from the lumbar portion of the spine to the thigh bones.

Between the thorax and the pelvis the skeleton is open in front, which gives room for continual variations in the capacity of certain of the abdominal organs concerned in digestion, and enables us to stoop and otherwise bend the trunk.

THE LIMBS.

The Upper and Lower Limbs obviously resemble one another in consisting each of three parts, which have evident correspondences,—viz., the arm corresponding with the thigh, the fore-arm with the leg, and the hand with the foot. The bones of these parts also correspond; but since the one is organized for prehension, and the other for support and locomotion, suitable modifications of size, form, arrangement, and mode of jointing together are of course met with.

The Upper Limb.

M.—Right *Humerus*, or *Arm-bone*, is a good example of a long bone. Its rounded upper end or head is fitted into the socket of the shoulder, formed by the glenoid cavity of the scapula; its lower end is flattened out and is jointed at the elbow with the two bones of the fore-arm—viz., by a pulley-like surface with the Ulna, O, and by a rounded eminence with the Radius, N.

N.—Right *Radius*, or *Spoke-bone*, the outside bone of the fore-arm.

O.—Right *Ulna*, or *Cubit*, the inside bone of the fore-arm.

The ulna enters largely into the elbow-joint, where it forms a hinge-joint with the humerus; at its lower end it is slender, and assists but slightly in forming the wrist-joint. On the contrary, the radius is small above at the elbow-joint, but below constitutes the greater part of the wrist-joint, where it forms the chief support of the hand. The radius has a very peculiar movement upon the ulna, rolling, as it were, upon it, and carrying the hand with itself. In this way the radius and ulna may cross one another, as shown in the left arm of this figure.

P. 8.—Eight small bones of the *Wrist* or *Carpus*, also called *Carpal bones.*

They are arranged in two rows, so as to give free movement, combined with elasticity, power of resistance to shock, and great strength to the wrist. The first row, counting from the side of the radius, comprises the *scaphoid*, the *semilunar* and the *cuneiform*, which latter supports a little roundish bone named the *pisiform*, or *pea-shaped bone.* The second row contains, beginning at the thumb, the *trapezium*, the *trapezoid*, the *os magnum*, or *great bone*, and the *unciform*, or *hooked bone.*

Q. 5.—Five long bones of the *Metacarpus*, called *Metacarpal bones.* They are firmly attached to the second row of carpal bones, support each a finger or thumb, and form the broad part of the hand. The metacarpal bone of the thumb stands away from the rest, and enjoys a special freedom of movement on the trapezium bone of the carpus.

T. 14.—Fourteen little bones, two for the thumb, and three for each finger. These are the finger-bones, or *Phalanges.* The first in each finger is attached to the corresponding metacarpal bone, and moves in several directions upon it. The others form hinge-joints only. The last supports the nail, and is called the *ungual* phalanx.

The Lower Limb.

W.—Right *Femur*, or *Thigh-bone.* These are the longest and largest bones in the body, and correspond with the humerus in the arms. The large globular *head* is sunk in the acetabulum at the hip-joint. The *neck* is the short piece, which forms an angle with the main part or shaft of the bone. The *shaft*, thrust outwards above to widen the base of support for the weight of the body, inclines inwards to the knee, to bring the base more under the centre of gravity. The large projections below are the *condyles*, the inner one being the longer, so that the femur may gain an horizontal bearing on the top of the principal bone of the leg at the knee-joint.

X.—Right *Knee-pan*, or *Patella.* This little bone protects the knee-joint: it belongs rather to the muscular system than to the skeleton proper, being placed in the tendon of a muscle.

Y.—Right *Tibia*, or *Shin-bone;* the inside and largest bone of the leg. It enters solely into the knee-joint above, and forms the prominence of the inner ankle below.

Z.—Right *Fibula*, or *Splint-bone*, the outside or small bone of the leg. It does not enter into the knee-joint, but forms the outer ankle below. The tibia corresponds with the radius, and the fibula with the ulna, in the upper limb; but, in order to obtain increased strength, the two bones of the leg are fixed firmly together, and have no movement one on the other like the corresponding bones in the fore-arm.

P.′ 7.—Seven short strong bones, forming the *Tarsus*, or *Tarsal bones.* The highest one alone enters into the ankle-joint; one large bone behind forms the heel. All of them assist in the construction of the *arch of the foot* (as explained more fully by aids of figs. 15 and 16).

Q.′ 5.—Five long bones of the *Metatarsus*, or *Metatarsal bones;* one for the support of each toe; that for the great toe being the strongest. They correspond with the broad part of the foot, and complete its arch in front.

T.′ 14.—Fourteen little bones, named *Phalanges of the Toes.* The great toe, like the thumb, has two; the other toes have each three. They are shorter and smaller than the phalanges of the fingers.

Figure 15.

The bones of the left foot seen from above, the leg-bones being taken away.

P.′ 7.—The solid part of the foot, or Tarsus, consisting of seven bones, not of eight as in the Carpus, or wrist, two bony pieces of which are here represented by one.

Q.′ 5.—The five Metatarsal bones, that for the great toe being considerably the largest.

T.′ 14.—The fourteen Phalanges of the toes; two for the great toe, three each for the other toes.

Figure 16.

The inner side of the lower ends of the leg-bones, and of the left foot, intended chiefly to show the bony *arch of the foot*, extending from the heel to the ball of the great toe. It is upon this arch that the weight of the body is transmitted through the corresponding leg.

Y.—Part of Tibia.

Z.—Part of Fibula.

P.′ 7, Q.′ 5, T.′ 14.—Same as in last figure. A little bone, shaped like a seed, is seen beneath the joint at the ball of the great toe. It is one of two bones found here, called the *sesamoid bones;* they are connected with the tendons of muscles, in the same way as the patella is at the knee-joint. There are two similar sesamoid bones in each thumb, but they are not represented in fig. 1.

In these two figures the separate tarsal bones may be readily distinguished. The highest, named the *astragalus*, alone enters into the ankle-joint, being received between the lower ends of the tibia and fibula, and having a large smooth surface, covered with cartilage (see fig. 15), on which the tibia rests. The astragalus rests behind on the *heel-bone*,—the largest tarsal bone, called also the *os calcis;* in front, it bears against the *scaphoid*, seen projecting slightly on the inner border of the arch of the foot. The *scaphoid* again presses in front against *three* wedge-like bones, named *cuneiform bones*, which support the three inner toes. Lastly, the *cuboid*, placed on the outer border of the tarsus, is locked in between the os calcis, the scaphoid, one of the cuneiform, and the metatarsal bones of the two outer toes. The os calcis represents the cuneiform and the pisiform bone of the wrist, and so diminishes the number of bones in the tarsus to seven.

THE JOINTS.

Figure 1 *(concluded).*

Wherever the different bones or pieces of the skeleton meet and are connected together, joints or articulations are formed. These joints (so to speak) break up the skeleton into levers, which, as fully explained in diagram No. 2, are employed in the varied movements of the body. Thus, the joints impart elasticity to the frame, determine the character of its attitudes and motions, and lessen shocks to the whole system. There are three kinds of joints, named, according to the degrees of movement they possess, the immovable, the movable, and the mixed.

The *immovable joints* are those in which two adjacent bones are fixed together at their borders, either by linear or serrated edges, as already exemplified in the sutures of the facial and cranial bones (figs. 1, 2, 3). Sometimes the edges of the two bones fit like a tenon-and-mortise joint; sometimes they are dovetailed; sometimes they overlap. Always a firm thin membrane, continuous with the periosteum, passes between the adjoining edges, and serves to hold them together, and prevent shock.

The *mixed joints* are those in which two bones are opposed to one another by broad and somewhat roughened surfaces, which are firmly but not immovably held together by an intermediate substance of a mixed fibrous and cartilaginous texture, named *interoseous* substance or ligament, and are strengthened outside by bands of fibrous membrane, which form the external *ligaments.* Such is the mode of junction of the bodies of the vertebræ with one another, of the two pieces of the sternum, and of the hip-bones with the sacrum behind, and with one another at the pubic arch. Here consult fig. 1.

The *movable* kind includes all the other joints in the body. In them, the opposed surfaces of any two bones are smooth, and covered with a closely adherent layer of a firm elastic substance, called *Cartilage.* The free surfaces of these cartilages touch and play one upon the other. Attached to both bones all round the borders of the cartilages is a membranous bag or sac, closed on every side, and called the *Synovial membrane,* or *capsule,* which contains a thick fluid, named *Synovia,* from its resemblance to the unboiled white of egg, and the purpose of which is to lubricate the joint. Outside this sac are strong fibrous bands of a dense whitish inelastic tissue, called *ligaments,* which strengthen the capsule, and hold the bones more firmly together. These movable joints differ very much in the form of their opposed surfaces: thus, some have flattish surfaces, and are capable only of *gliding* movements, as most of the small joints of the wrist and ankle; others have *pulley-like* surfaces, and a principal motion in two directions only, like a hinge, as the elbow, knee, wrist, ankle, and phalanges of the toes and fingers; lastly, others have one surface like a *socket,* and the other like a *ball* fitting into it, and possess free movement in all directions, as the shoulder and hip joints, and the roots of the thumbs, fingers, and toes.

There is one set of ligaments in the body, namely, those which connect together the back part of the rings of the movable vertebræ one with another, which are not composed of inelastic fibrous tissue, but of a peculiar yellow tissue, called, from its property, *elastic tissue.* Its presence in the above-named situation facilitates the bending forward of the vertebral column.

In this diagram the outward appearances only of certain joints are shown, so as to display their connecting bands or ligaments. The interior of some of the movable joints is illustrated in diagram No. 2, figs. 5 to 8.

The structure of cartilage and fibro-cartilage, synovial membrane, ligamentous and elastic tissue, is given in diagram No. 9.

Joints of the Upper Limb.

a.—Ligaments connecting the inner end of the left collar bone with the top piece of the breast-bone and the first rib, showing the mode in which the upper limb is supported on the trunk.

b.—Ligaments connecting and suspending the left blade-bone, or scapula, to the outer end of the left collar-bone.

c.—Ligaments connecting the humerus, or arm-bone, with the left blade-bone, to form the shoulder-joint, which is also embraced and strengthened by many muscles and their tendons. A section of this joint is shown in diagram No. 2, fig. 5.

d.—Ligaments connecting the ulna and radius, or bones of the fore-arm, with the humerus, at the elbow-joint.

The ligaments which tie the radius and ulna themselves together in such a way as to allow the former to roll upon the latter, are shown in diagram No. 2, fig. 6.

e.—Ligaments on the back of the wrist-joint, connecting certain of the bones of the carpus with the radius and ulna.

f.—Ligaments connecting the carpal bones with one another, and certain of them with the metacarpal bones.

i.—Ligaments of the finger and thumb joints.

Joints of the Lower Limb.

g.—Ligaments of the left hip-joint, connecting the left thigh-bone, or femur, with the left hip-bone, or innominate bone. A well-marked bundle of fibres strengthens the fore part of the joint. A section of it is shown in diagram No. 2, fig. 7, in which an internal ligament, peculiar to this joint, is represented.

h.—Ligaments of the left knee-joint, connecting the knee-pan and leg-bones,—the patella, tibia, and fibula,—with the femur, or thigh-bone. The knee-pan strengthens and protects the joint in front; it receives a strong tendon from the extensor muscles above (of which a piece is here shown), and gives off another band below, marked j. The knee-joint is strengthened by the tendons of many muscles, and by a strong fibrous membrane, called a fascia, which surrounds the muscles of the lower limb. It also possesses strong internal ligaments, shown in the section of the joint in diagram No. 2, fig. 8.

j.—The so-called ligament of the patella,—in reality a continuation of the tendon of the extensor muscles above,—which ties that bone to the tibia, or shin-bone.

k.—A broad fibrous membrane, connecting the two leg-bones, named the interosseous membrane. It serves chiefly to give origin to muscles.

l.—Ligaments of the ankle-joint, connecting the tarsal bones with the leg-bones. Other ligaments, tying the tarsal-bones together, are also seen.

m.—Ligaments connecting the metatarsal with the tarsal bones. Example, the great toe.

n.—Ligaments connecting the bones of the toes with the metatarsus. Example, the great toe.

Joints of the Trunk.

o, o.—Examples of some of the ligaments which connect the ribs to the back-bones, or dorsal vertebræ.

Radiating bands of ligaments are also shown, connecting the cartilages of the seven upper ribs to the breast-bone, or sternum.

The two pieces of the sternum are joined partly by external, but chiefly by intermediate or interosseous ligaments.

The small joints of the vertebræ, one with another, are not shown in this figure; but the edges of the *intervertebral substances*, or fibro-cartilaginous and ligamentous structures which join the bodies of the vertebræ, are plainly seen in the neck, and especially between the lumbar vertebræ and between the last vertebra of the loins and the sacrum.

r, s.—Ligaments on the left side of the pelvis, which connect the left innominate bone, or hip-bone, with the corresponding side of the sacrum, and with the last lumbar vertebra. There are also strong interosseous ligaments between the sacrum and hip-bone.

The two innominate bones are tied together in front by external ligaments crossing from one to another, and by interosseous ligaments.

All the joints, the ligaments of which are referred to by letters from 'a' to 'o, o,' are movable joints; the succeeding remarks refer to joints belonging to the mixed kind.

A white fibrous cord, shown in the figure, passing from the left ilium to the pubic bone, named *Poupart's ligament*, serves to strengthen the lower part of the walls of the abdomen, and belongs properly to the muscles of that region.

No. 2.—The Muscles, Joints, and Animal Mechanics.

THE chief figure in this diagram displays the greater number of the *superficial muscles* of the human body, and, on being studied with the subsequent description, will be found to illustrate most of the general statements therein contained respecting the *Muscular System.*

Figs. 2, 3, and 4 represent examples, selected from the human frame, of the three kinds of mechanical arrangements denominated *Levers.* They are described after fig. 1.

As the remaining figures, 5 to 8, relate to the structure of joints, a subject already partly illustrated in diagram No. 1, their description is intentionally put first in order.

THE JOINTS.

Figures 5 to 8.

The peculiar mode in which the radius and ulna are connected together in the forearm is represented in fig. 6; whilst figs. 5, 7, and 8 show respectively the interior of the shoulder-, hip-, and knee-joints.

In the three last-mentioned figures, the joints are supposed to be laid open by cutting through the bones which enter into their formation, so as to obtain the view called a *Section.* The cut surfaces of the bones show the difference between the outer dense or compact bony tissue, and the inner, more open, spongy, or cancellated texture, in which the blood-vessels and marrow are placed. The surfaces of the bones which enter into the joints are seen to be shaped so as to fit one to the other, and, moreover, to be covered with a thin closely-adherent layer of *cartilage* quite smooth on its free surface. It will be observed that in these figures the bones are drawn a little asunder, in order to display more distinctly the cavities of the joints, marked C, which, in each case, are seen to be limited by the *synovial membrane* connecting the two bones, and attaching itself near to the edges of their respective cartilages; so that, as in all movable joints, the synovial membrane forms a shut sac. During life, however, it must be remembered that the cartilages covering the ends of the bones are in contact, and that the sides of the synovial capsule fit so closely around them, as only to leave room for a very small quantity of the viscid fluid called *synovia,* which keeps the joint moist, and serves the double purpose of preventing loss of power by friction, and pain from the effects of a grating movement.

The following special references will explain all the details of these figures of the joints.

Fig. 5, is a vertical section through the left shoulder-joint. S, is a part of the scapula sawn through at the glenoid cavity or socket of the joint. H, is a section through the rounded head and upper part of the humerus or arm-bone. C, the synovial cavity of the joint, displayed by separating the bones, and seen to be bounded in other directions by the synovial membrane or capsule. The tendon of a muscle, viz. the biceps muscle of the arm, marked *t*, passes through this joint, as hereafter illustrated in fig. 4.

Fig. 6, shows the peculiar mode in which the radius is connected by ligaments and joints with the ulna, so as to allow the former bone to roll upon the latter in those movements by which the hand is placed alternately with the palm upwards and downwards. When the palm is turned upwards, the hand is said to be *supine*, and the movement by which this position is attained is called *supination;* and when the palm is directed downwards, the hand is said to be *prone*, and the corresponding movement is called *pronation.* Now, in these motions, it is the radius which moves, *with the hand*, upon the ulna, which is fixed by its upper end being locked into the lower end of the humerus at the elbow. In the state of supination, the bones are parallel to one another, as shown in the right arm of the skeleton in diagram 1; but during pronation, as shown in the left arm, the radius crosses obliquely over the ulna. The reason of this is explained by the mechanism of the intermediate joints. The radius, marked R, in fig. 6 of the present diagram, and the ulna, U, are also seen as in the supine position. They are connected along the greater part of their opposite borders by an intermediate fibrous membrane, called the *interosseous membrane*, which limits but does not wholly restrain movement, and which also serves as a surface of origin to certain muscles. At the lower end, the radius is tied to the ulna by the *inter-articular ligament*, I; and, at the upper end, it is closely embraced by a collar or ring of fibrous tissue, called the *annular* ligament, A, the two ends of which are fixed to the side of that part of the ulna. Where the bones touch each other, near their upper and lower ends, they are provided with smooth cartilage-covered surfaces, the radius being received into a hollow on the side of the ulna above, and the ulna into a hollow on the side of the radius below: in this way the rolling movement of the radius on the ulna is easily performed, whilst the ligaments just described retain the bones in apposition. This supination and and pronation are highly useful and characteristic movements of the upper limb; and they contrast, as already pointed out, at page 13, with the fixed condition of the corresponding parts in the leg.

Fig. 7, is a vertical section of the left hip-joint. I, is part of the innominate bone, cut through at the acetabulum or socket of the hip-joint, and also through the obturator foramen. F, is the upper part of the femur or thigh-bone, sawn longitudinally, showing its globular head, which fits into the acetabulum, its neck, the prominences called the *trochanters*, and part of the shaft. C, the cavity of the joint, bounded by the synovial capsule and the ligaments, and displayed by separating the bones a little. T, is the *ligamentum teres* or *round ligament*,—an internal ligament, quite peculiar to the hip-joint which ties the head of the femur to the bottom of the acetabulum. This ligament exists also in the monkey tribe generally, but not in the ourang-outan, though it does in some quadrupeds.

Fig. 8, is a vertical section of the right knee-joint, made from before backwards. F*e*, is the lower end of the femur cut through, showing the projection called the outer condyle. T, is the upper end of the tibia sawn through, showing the edge of the broad surface on which the outer condyle of the femur rests. Between these bones, certain fibro-cartilaginous pads, called *interarticular cartilages*, fit in during life, but they could not be represented in the figure. P, is the patella cut down its middle, showing the mode in which it enters into the formation of the knee, and protects that joint in front. By comparing this figure with fig. 1, the connection of the patella with the tendon of the extensor muscles of the thigh, marked 51, 52, and 53, will be understood. C, is the cavity of the joint, made more distinct by the separation of the cartilaginous surfaces, and bounded by its synovial capsule, which may be easily traced. L, shows a part of certain special internal ligaments, called the *crucial ligaments*, which bind the femur and tibia so strongly together. It is further seen that the patella is connected by a strong ligament with the tibia, but only by the synovial membrane with the femur. S, is a small synovial sac, called a *bursa* or purse, which lies between the ligament of the patella and the front of the tibia, and facilitates the movements of one on the other: it is distinct from the sac of the knee-joint. Some fat, filling up space between the bones and ligaments, is shown at *f*. F*i*, is the upper end of the fibula, which, it may again be remarked, does not enter at all into the formation of the knee-joint.

The perfection of the mechanical contrivances found in the various joints may be duly appreciated by the reader of the descriptions given with this and the preceding diagram.

THE MUSCLES.

Figure 1.

The large quantity of soft *reddish tissue* which surrounds the bones, and is itself covered by the common integuments, is called the *flesh*. When it is closely examined, this flesh is found not to consist of one uniform mass, but to be arranged in many portions or masses of various shape and size, which are called *Muscles;* such, for example as are marked by separate numbers in the present figure. The entire set of muscles constitutes the *Muscular System*. As seen in the diagram, the muscles occupy far more space than the bones, and indeed they form a larger portion of the body than any other system of organs. The red tint here employed in colouring the muscles, only approximates to the natural hue, which is familiar to all in the flesh of slaughtered animals. The integuments covering the muscles, viz. the skin and underlying fat, are represented in the diagram by an external outline or border of a yellowish tint.

The microscopic structure of flesh or muscular tissue is fully described in the account of diagram No. 9; but it is necessary to anticipate here so much by way of explanation, as to state that it consists of bundles of distinct and peculiar fibres, called *muscular fibres*, which possess during life the remarkable and hitherto unexplained vital property of *contractility*, that is, the power of shortening themselves when they are subjected to stimuli of various kinds. A number of these fibres arranged parallel to one another form a small bundle, and it is by aggregations of such bundles, held together by a delicate non-contractile tissue, called *areolar* tissue, that the definite masses are produced, which, under distinct names, are spoken of as muscles;—such as the *sartorius* muscle, 54, the *pectoral* muscle, 18, and so on.

There are about four hundred such muscles in the human body, distributed in pairs, equally and symmetrically on the two sides of the median plane.

In size and form, as seen in the diagram, the muscles present great variety. On the trunk they are for the most part large, broad, and flattish; in the limbs they are usually narrower and lengthened. The broad muscles again are either square, triangular, lozenge-shaped, or elliptical in their outline, and smooth or indented at their edges; the long muscles are either flat and ribbon-shaped, or round and fusiform, or penniform, &c. Some muscles, such as those of the eyeball and drum of the ear are very minute, whilst others, as the large muscles upon the thigh, called the *vasti* muscles, 52, 53, weigh several pounds.

The muscles are placed in layers, one upon the other. Some few, lying close to the skin, are attached only to it and to the subjacent soft parts,—as the elliptical muscle, 7, which surrounds the opening of the mouth. Another set more numerous, are attached by one end to bone and by the other to the skin, or to some soft part or organ,—as certain muscles of the face, which act on the lips, 5, 6, those which move the eyeballs (diagram No. 8, fig. 21), and also some of the muscles of the tongue (diagram No. 6, fig. 3). By far the larger number of muscles, however, are attached by both ends to the skeleton, passing from one bone to another.

That attachment of a muscle which is nearer to the centre of the body, usually the more fixed attachment, is called the *origin*, whilst the more distant, which is also usually the more movable attachment, is named the *insertion*. Sometimes a muscle has two points of origin named heads, as in the case of the biceps muscle of the arm, 22 (see also fig. 4, P); sometimes three, as the triceps of the arm, 25; sometimes many, as the great serratus muscle of the trunk, 21. Again, muscles may have more than one point of insertion, as in the case of the long muscles of the fingers, 29, and toes, 62. On the trunk, most of the muscles pass over more than one joint; in the limbs, too, although a few pass over one joint only, the greater number extend over two or more joints.

The muscles are sometimes fixed to the bones, by minute and scarcely visible slips of fibrous tissue, which are connected firmly to the periosteal covering; but more frequently they are less directly attached, as may be seen in the diagram, by strong white flexible but inelastic cords called *tendons*, which consist of fibrous tissue, and present great variety in size and shape,—being either flat, broad, conical, or folded on themselves, and sometimes long and thin, or long and thick, like slightly compressed cords.

The muscular fibres usually either spring from or are inserted into the sides or surfaces of these tendons, which are themselves attached to the bones; so that many more of the contractile fibres are thus enabled to act upon a given point of the skeleton than if those fibres themselves all reached the bones. So too the muscular force is more conveniently reflected over bony surfaces or joints by cord-like and almost insensible tendons, which are usually lodged and secured in appropriate grooves, than it could be by a broad expanse of soft and sensitive tissue, like muscle. Lastly, a combination of strength with economy of muscular fibre is hereby effected, and, especially in the limbs, lightness and elegance of form are secured.

Now when a muscle is in action, the peculiar vital property of contractility possessed by its fibres coming into play, its whole mass shortens itself in the direction of its common axis. Hence its points of attachment, or, in other words, its origin and insertion, if movable, are drawn towards each other, or else that end which for the time is more movable, is drawn towards that which is more fixed; and according as such attachments are to soft parts only, or to bone at one end and to soft parts at the other, or to bone at both ends, so the action of the muscle alters the shape and tension of the soft parts, pulls these latter towards the bones, or disturbs the direction of one, two, or more pieces of the skeleton at some joint or joints, after the manner of levers in mechanics, as is more particularly explained under figs. 2, 3, and 4.

If a muscle with its tendons passes over only one joint, as in the case of the deltoid, 19, it can act only on that joint; if it extends over several, as in the instance of the muscles of the fingers, then it may influence them all in succession, beginning usually at the joint most remote from the fixed end of the muscle. The character and extent of the movements thus produced, of course depend on the nature of the joints and the form of their surfaces; so that hinge-joints are merely bent or straightened, whilst a ball-and-socket joint may also become the seat of lateral or of rotatory motions.

In this way all the countless motions of the body and limbs are performed. Muscular contraction is invariably the power employed, and the various anatomical arrangements above described, relative to the number and disposition of the muscles, their size and form, and their modes of attachment, whether to soft parts or to bones, are examples of the remarkable variety of contrivance by which this single force is applied or utilized to so many purposes in the living body.

It must not be forgotten that when a muscle is in action, it not only becomes shorter, but swells out or increases in thickness (see the biceps at rest and in action, fig. 4, P); and hence, besides those changes of form which are due to movements occurring at the joints, most important variations of shape on the surface of the body are produced by muscular exertion.

Two important adjuncts to the muscular system require to be noticed here. First, there is always a quantity of loose non-contractile *areolar* or *connective tissue*, which surrounds and connects different muscles together, supports their nutrient vessels and nerves, and enables them to glide easily upon each other whilst in action.

Secondly, in certain situations there is found a strong fibrous investment, which not only embraces and supports the muscles of an entire limb, and binds down their tendons securely, where these pass over the joints, but also forms firm partitions or sheaths between or around such muscles as from their length or oblique direction have a special tendency to be displaced during movement.

This common investment is named the *fascia*. It is shown in diagram No. 3, fig. 1, covering the muscles and tendons of the upper and lower limbs, in which situations, it is stronger than on the trunk. The muscles and tendons are distinguishable through the fascia, which, as shown on the left side, supports the superficial blood-vessels, and (as indicated in diagrams Nos. 5 and 7), the superficial absorbent vessels and nerves also. On the outer side of the limbs it is thicker than on the inner, and also around most of the joints. At the wrist and ankle it is strengthened by circular bands called *annular ligaments* (shown in the present diagram in fig. 1, *aa*, and *ll*, and also in diagram No. 3, fig. 1, *l*, *l′*), which serve to secure the tendons in their appropriate grooves, and prevent their starting way from the bones when the muscles are in action. The tendons of the flexor muscles of the fingers, *b*, and the toes, have strong special sheaths for this purpose quite independent of the fascia.

As shown in diagram No. 3, fig. 1, the fascia is very strong in the palm of the hand, *e*, where it covers and supports the tendons, muscles, vessels, and nerves. It is even thicker in the sole, where it serves the additional purpose of strengthening the arch of the foot. In certain situations muscles are so attached to the fascia as to be able to make it more tense, as the biceps and the long palmar muscle in the forearm (see diagram No. 3, fig. 1, right upper limb), and the tensor muscle as the fascia of the thigh, 50, 50′, in the present diagram. In the face there is no fascia properly so called, but the muscles lie close beneath the skin and fat.

Modes of Action of the Muscle.

The muscles of the head, trunk, and limbs, now under consideration, are named *voluntary muscles*, because they are subject to the will, which acts upon them through the intervention of the nervous system (see diagram No. 7). But, as will have hereafter to be explained, there are in the body other muscular structures also endowed with the vital property of contractility, though not under the control of the will, called *involuntary* muscular structure. Such are the heart, and the muscular coats of the alimentary canal, of the air-tubes and of the larger blood-vessels.

In the case of the voluntary muscles, the will may set a single muscle in action, as in raising the upper eyelid; but this is the exception to the rule, and in general, many muscles combine or co-operate to perform one voluntary act,—as in the several movements of a limb, or of the whole body. Indeed, in most movements, every muscle of the body concurs, more or less, either in fixing certain parts of the skeleton, or in moving other parts.

It is by voluntary muscular action that we accomplish every kind of progressive movement or locomotion, perform every change of posture, and assume and maintain every fixed attitude. The movements of offence and defence, the lifting and bearing of weights, prehension or seizing things with the hands, labour of the rudest and manipulations of the most delicate kind, the taking of food or drink into the mouth, mastication and the first stages in the act of swallowing, the act of blowing or whistling, the utterance of voice and its conversion into speech or song,—are all instances of complex voluntary muscular movement. So, too, this comes in aid of the more exact or critical exercise of the organs of the senses,—as in feeling anything carefully, smelling or tasting wine, listening attentively, and fixing the eyelids and the eyes.

But the voluntary muscles also perform many involuntary movements, which are of two kinds—

First, there are all the outward manifestations of emotion or passion,—as trembling, gasping, choking, holding the breath, frowning, crying, and laughing. Secondly, there are such acts as winking to protect the eye, sneezing and coughing to protect the nose and air-passages, spasm of the muscles which close the entrance to these passages against noxious gases, and lastly, the act of breathing itself, especially as performed unconsciously during sleep.

All these, and other similar movements, being executed by voluntary muscles, it cannot be a matter of surprise that they may each be modified, controlled, arrested, or even imitated by the will; nevertheless, they are ordinarily involuntary acts, and indicate two modes of action of the muscles, independent of the will,—one called *emotional*, the other *reflex*, which, as will hereafter be explained, are as strictly performed and regulated through the intervention of the nervous system, as the voluntary movements themselves. (See diagram No. 7.)

Names of the Muscles.

Every muscle has at least one name—many of them have several names. These are derived either from their most evident action,—as the *flexor* of the wrist, 37, because it bends the wrist, and the *extensor* of the wrist, 27, because it straightens that joint; or from their form,—as the *triangular* muscle of the mouth, 9; or from their construction,—as the *biceps* muscle of the arm, 22; or from their situation,—as the *anterior tibial*, 61; or from their direction,—as the *straight* or *rectus* muscle of the thigh, 51; or from their origin and insertion,—as the *sterno-mastoid*, 15; or from some other circumstance,—as the *sartorius* or *tailor's* muscle, 54, because it assists in crossing one leg over the other.

In the following list of the particular muscles represented in the diagram, their most descriptive names are selected; and at the same time their principal, but by no means their only, actions are briefly indicated. It will be found to suggest many points for the instruction or examination of pupils.

It has not been considered desirable to occupy space by describing the points of attachment of the muscles to the skeleton, but in many instances these are sufficiently evident, especially on comparing this figure with fig. 1 in diagram No. 1.

It will be useful first to attend carefully to the following references to certain parts not muscular.

Bony and Ligamentous Parts shown in this Figure.

*	Sternum or breast-bone.
a a	Annular ligament of the wrist, part of the fascia of the upper limb, front and back views.
b	Fibrous sheaths of the flexor tendons of the fingers, which bind those cords down to the bones and secure them, whilst the flexor muscles are in action.
c	Prominence caused by the larynx, or organ of voice.
e	Clavicle or collar bone.
f	Point of the acromion process of the scapula or shoulder-bone.
g	Margin of the hip-bone or ilium.
h h	Patellæ or knee-pans, right and left, each receiving the conjoined tendons of the rectus, 51, and vasti muscles, 52, 53, above, and attached by the ligamentum patellæ to the tibia below.

i Tibia or shin-bone.

l, *l* Annular ligament of the ankle, part of the fascia of the lower limb, inner and outer view.

Muscles of the Head and Face.

1 Frontal and 1′ Occipital portions of the occipito-frontal muscle, united by a broad tendon over the top of the cranium; moves the scalp, and wrinkles the forehead horizontally.

2 Temporal muscle; closes the teeth as in chewing.

3 Orbicular of the eyelids; closes the eyelids.

4 Compressor of the nose; acts on the cartilages of the nose.

5 Levators of the nose and upper lip; raise the lip and side of the nose.

6 Zygomatics; used in laughing, to extend the corners of the mouth.

7 Orbicular of the mouth; closes the mouth.

8 Square muscle of the chin; depresses the lower lip.

9 Triangular or depressor of the corner of the mouth; draws down the corner of the mouth.

10 Buccinator or cheek-muscle; keeps the food between the teeth; compresses the air in blowing a trumpet.

11 Masseter; closes the teeth in mastication.

Muscles in the Neck.

12, 12′ Digastric; opens the teeth by lowering the under jaw.

13 Sterno-hyoid; draws down and fixes the hyoid bone, or bone which supports the tongue.

14, 14′ Omo-hyoid; has a similar action, especially it is said in sucking.

15 Sterno-mastoid; turns the head and face to the opposite side.

16 Part of the trapezius; has many actions on the head and shoulders.

17′ Splenius; helps to support the head from falling forwards.

Muscles on the Trunk.

18, 18 Right and left great pectorals; move the arm-bones forwards and downwards.

19, 19 Right and left deltoids; raise the arm-bones.

20 Edge of the latissimus dorsi, or broadest muscle of the back; draws the arm-bone backwards and downwards, and rotates it inwards.

21 Great serratus muscle of the scapula; draws the shoulder-bone forwards.

Muscles on the Upper Limb.

22, 22 Right and left biceps; flex or bend the forearms on the arms, and in each case, being inserted into the radius only, roll that bone outwards on the ulna, and so help to supinate the hand. (See fig. 4, P.)

23, 23 Right and left anterior brachials; merely bend the forearms on the arms, being inserted, on each side, into the ulna only.

24 Right coraco-brachial; draws the arm to the side.

25 Right and left triceps; extend or straighten the forearms on the arms.

26, 26 Right and left long supinators; turn the palms of hands and wrists face upwards, or supine.

27} 28} Left radial extensors of the wrist; extend the wrist on the forearm.

29 Common extensor of the fingers; extends or straightens the fingers.

29′ Tendons of the same.

30 The three extensors of the thumb; extend the three bones of the thumb.

31 Extensor of the little finger; straightens that finger.

32 Ulnar extensor of the wrist; extends the wrist on the forearm.

33 Abductor of the forefinger; draws that finger from the middle finger.

34 Adductor of the thumb; draws the thumb to the palm of the hand.

35 Interosseous muscles of the back of the hand; draw fingers aside.

36 Pronator of the radius; helps to turn the palm of the hand face downwards, or prone.

37 Radial flexor of the wrist; helps to bend the wrist on the forearm.

38 Long palmar muscle; tightens the palmar fascia. (See diagram No. 3, fig. 1, e.)

39 Superficial flexor of the fingers; bends the second bones of the fingers.

39′ Tendons of the same.

40 Ulnar flexor of the wrist; helps to bend the wrist on the forearm.

41 Short palmar muscle; raises the skin on the inner border of the palm.

42 Short muscles of the thumb; draw the thumb in different directions.

43 Termination of one of the tendons of the deep flexor of the fingers; acts on last bone of each finger.

44 Lumbricales muscles of the palm of the hand; assist the flexors of the fingers.

Muscles on the Trunk.

45 Left external oblique muscle of the abdomen; helps to support the viscera, and acts on the thorax so as to bend or turn the trunk.

45′ Linea alba, or white line of the broad tendons of the abdominal muscles; these tendons support the contents of the abdomen in front.

46, 46 Bulgings produced by the left rectus muscle underneath.

47 Tendinous arch, called Poupart's Ligament.

48 Great gluteus muscle; erects the pelvis on the femur.

49 Middle gluteus muscle; has a similar action.

Muscles on the Lower Limb.

50, 50 Right and left tensor muscle of the fascia of the thigh; tightens that fascia, and acts on the knee-joint.

50′ Part of this fascia, through which the last-named muscle acts on the knee.

51, 51 Right and left rectus or straight muscle of the thigh; extends the leg on the thigh.

52, 52 Left external vastus muscle; has a similar action.

53 Right internal vastus muscle; has a similar action. The rectus and two vasti

muscles erect the thigh-bone on the tibia. They also extend the leg on the thigh, acting on the tibia through the patella and ligamentum patellæ.

54, 54 Right and left sartorius or tailor's muscle; draws one leg over the other, and bends it.

55, 55′ Adductor muscles of the thigh; draw the thigh inwards; also steady the pelvis on the thigh-bone.

56 Semi-membranosus muscle; helps to bend the leg on the thigh.

57 Biceps flexor muscle of the left leg; helps to bend or flex the leg.

58, 58 Right and left gastrocnemius muscle; keeps the leg erect on the ankle, extends the foot, and also raises the heel in walking.

59, 59 Soleus muscle in each leg—assists the last-named muscle; both of them act upon the os calcis through the largest tendon in the body, named tendon of Achilles, because it corresponds with the vulnerable part of that famous Greek hero.

60, 60 Left peroneal muscles; steady the leg on the ankle, also turn the foot outwards.

60′ Tendon of the small peroneal muscle; raises the foot.

61 Left leg. Anterior tibial muscle; raises the foot.

61 Right leg. Tendon of the same.

62 Left leg. Common extensor of the toes; raises the foot, but especially extends or pulls up the four outer toes.

62′ Tendons of the same.

62 Right leg. Tendon of the long extensor of the great toe; also seen in the left foot, but not marked; raises that toe.

63 Right posterior tibial; stretches the foot and turns it in.

64 Left short extensor of the toes; helps to raise the four inner toes.

64′ Tendons of the same.

65 Abductor of the little toe; draws that toe from the others.

66 Abductor of the great toe; draws that toe from the others.

The reader may now refer to the description of diagram No. 4, in fig. 1 of which many of the muscles are again shown under different aspects.

Figures 2, 3, and 4.

Examples of Levers in the Human Body.

A lever in mechanics consists of some rigid substance usually shaped like a rod or bar, which rests on a *fulcrum* or point of support, has connected with it a *weight* to be moved, or has some resistance to be overcome, and is acted upon by a *power* or force which moves the weight or overcomes the resistance.

There are three kinds of levers, designated first, second, and third, and distinguished from each other by the relative position or arrangement in them of the fulcrum, weight, and power. In the first the fulcrum occupies the middle place; in the second, the weight; in the third, the power.

The first kind of lever is employed in working a pump-handle; the second in using a wheelbarrow; the third in drawing a ladder from a wall, by pulling on one of the rounds near the bottom, whilst the foot is so placed as to prevent it slipping out.

Examples of all three kinds of lever are found in the human body,—the bones constituting the rigid rods or bars, whilst the muscles are the sources of power. The third kind, which is the least frequently employed in ordinary mechanics, is the most common in animal mechanics.

Fig. 2.—The first kind is exemplified in the connection and movements of the skull upon the first vertebra of the neck.

In this case, the fulcrum, F, is the first cervical vertebra; the weight, W, is the excess of weight of the parts of the head and face in front of the fulcrum over that of the parts behind it; whilst the power, P, is exerted by the muscles of the back of the neck, which extend from the spine to the cranium.

The rocking movements of any one vertebra on that immediately below it, those of the lowest lumbar vertebra on the sacrum, and those of the pelvis on the thigh-bones in assuming the erect posture, are performed after the same manner. So likewise is the *extension* of most of the joints in the limbs, as the elbows, ankle-joints, knees, and knuckles.

It will readily be perceived that the chief use of the projecting processes of bone to which the muscles are attached, is to throw out the point on which the power acts as far as possible from the centre of movement at the fulcrum.

The projection of the ulna behind the elbow, and also that of the heel, are good examples of this; and it may be remarked that the patella, though a detached bone, serves a similar purpose at the knee-joint.

Fig. 3.—The second kind of lever is illustrated in the foot, when resting on the ground with the heel raised.

Here the fulcrum, F, is the ground beneath the ball of the great toe; the weight, W, is that of the body transmitted through the leg; whilst the power, P, acts through the muscles of the calf, pulling, by the tendon of Achilles, on the heel-bone. The depression of the lower jaw, in opening the mouth, affords another illustration of this kind of lever.

Fig. 4.—The third kind of lever is employed in the various joints of the limbs, but especially in the flexion or bending of those joints; also in the movements of the ribs, and in raising the lower jaw.

A good example occurs at the elbow-joints, when the hand and forearm are being raised, either with or without any object being in the hand.

Here the Fulcrum, F, is in the elbow-joint; the weight, W, is the forearm and hand; whilst the power, F, is in the biceps muscle, which, arising by two heads from the shoulder-bone, is inserted below into the radius, and by its contraction draws the forearm and hand upwards.

The resulting changes of position and form are indicated by the faintly-tinted parts. Since in this and other similar cases, the muscular force acts so much nearer to the fulcrum than to the weight, there is an enormous expenditure of power to obtain a given end; but, just in the same ratio, the required advantage of velocity of movement of the end of the lever is obtained; for it is obvious that if the point of insertion of the muscle is distant from the fulcrum one-tenth the length of the lever, the end of the latter goes through nine times the space that the point of insertion of the muscle has to travel.

No. 3.—The Viscera in Position. The Structure of the Lungs.

Besides showing the fascia upon the muscles of the limbs, the principal superficial blood-vessels of the head, face, and left upper and lower extremities, and certain deep-seated parts in the neck, the central figure, marked 1, in this diagram, exhibits, in their natural position, the parts or organs found in the two great cavities of the trunk, viz. the *Chest* and the *Abdomen*, or soft part of the body.

These organs are also named *Viscera* (in the singular number, *viscus*), a term which is applied to such organs only as are placed in one of the three great cavities of the body, viz. the head, chest, and abdomen; so that the eye is not a viscus, nor yet the tongue, but the brain, heart, and liver are viscera.

The remaining figures of this diagram, figs. 2 to 9, with the exception of fig. 5, illustrate the anatomy of the breathing organs, or *Organs of Respiration;* and also the connection of these with the organs of circulation of the blood.

Fig. 5, is a plan showing how the cavities of the chest and abdomen, here represented empty, are separated from each other by a vaulted partition,—certain regularly-repeated changes in the position of which connected with the act of breathing, are likewise illustrated in it.

In the central figure, and it may be here observed, in the principal figure in diagrams Nos. 4, 5, and 7, the tints employed approximate to the natural colours, after death, of the parts represented. In the detached figures the colouring is mostly conventional, and the same is true of the colours which distinguish the two kinds of blood-vessels, named *arteries* and *veins*, the former being tinted *red* and the latter *blue*, which are quite conventional colours. In the case of certain blood-vessels connected with the lungs, shown in fig. 3, the arteries are blue and the veins red, an exception the reason for which will appear in the sequel.

Figure 1.

The fascia of the limbs having already been described with diagram No. 2, page 21, and the superficial blood-vessels of the head, face, and limbs being more appropriately reserved for consideration in the account of diagram No. 4, brief references only will here be made to those parts.

Then will follow an explanation of the names and general position of the viscera in the thoracic and abdominal cavities; and lastly, some space will be devoted to a particular account of the structure and use of the breathing organs.

The Fascia and Blood-vessels.

a Curved part of the aorta; the great arterial vessel which conveys blood from the heart to the body.

c Right carotid artery, which carries blood to the head and face.

f Right facial artery and its accompanying vein; the former conveying blood to the face, and the latter returning it.

t Right temporal artery and vein, which carry blood to and from the scalp.

j Right jugular vein, through which blood returns from the head and neck towards the heart.

b Right subclavian vein, which conveys blood returning from the upper limb. The jugular and subclavian veins unite in a common trunk, called the right innominate vein, which then joins the corresponding vein on the left side, viz.—

i The left innominate vein. The two innominates end in a great venous trunk (not seen in this figure) which descends to the heart.

d One of the superficial veins of the arm, returning blood from that limb; it is generally selected for the operation of blood-letting.

ss Great saphenous vein, the principal superficial venous trunk for the return of blood from the lower limb.

p The pulmonary artery which conveys blood from the heart, C, to the lungs. Observe that, although an artery, it is coloured blue.

e Fascia of the palm, or palmar fascia, having the tendon of the long palmar muscle attached to it above, and spreading out below towards the fingers. On the balls of the thumb and little finger it is thin.

l Annular ligament of the wrist, formed by circular bands of the fascia of the forearm, and serving to bind the tendons of the muscles.

l' Annular ligament of the ankle, formed in a similar way, and serving similar uses.

The Thorax and the Abdomen, with their contained Viscera.

The bony frame-work of the *thorax* or chest, already shown and described, diagram No. 1, page 10, forms a conical cage, narrow and open above, wide and open below, and, even at the sides, consisting of an open-work of bones. In the perfect state, however, the walls of the thoracic cavity are completed by muscles, membranes, and other soft parts. Thus, its upper aperture is occupied by certain tubes, vessels, and nerves, which there pass in or out of it. At the sides, the interspaces between the ribs are filled up by thin muscles called *intercostal* muscles, shown in diagram No. 5, fig. 1, which act upon the ribs; and there are likewise broad muscles which cover those bones, and act more or less upon them. Lastly, the wide-opening of the chest below is filled in by an important structure called the *Diaphragm*, DD, which is a thin partition, partly muscular and partly tendinous, attached to the vertebral column behind, and to the lower margin of the thorax all round, and arched upwards like a vault, as shown in the plan, fig. 5, D, and also in diagram No. 4, fig. 1.

The diaphragm separates the chest from the abdomen, being at once the floor of the former and the roof of the latter cavity. Certain tubes, vessels, and nerves pass through special openings in it. Being chiefly muscular, it is of course capable of contracting, and hence of undergoing important changes in position and form, as will soon be explained.

The cavity called the *abdomen* corresponds with the soft part of the trunk, commonly known as the belly. It is placed in front of the vertebral column, having the diaphragm above and the pelvis below, and is inclosed at the sides and in front by muscular and membranous walls only, which stretch from the lower margin of the thorax to the pelvis. There are three layers of broad muscles at each side, the strong wide tendons of which are continued over the front part, which is further strengthened by a pair of straight muscles. See diagram No. 2, fig. 1, 45, 45′, 46, 46.

The cavity of the abdomen ascends within the ribs as high as the vault of the diaphragm, and is continuous below with that of the pelvis. It is larger, as well as more variable in form and size, than the cavity of the thorax, in this way adapting itself to the frequent changes of bulk which take place in the digestive organs.

In the central figure of the present diagram, the chest and abdomen are laid open by removing their anterior walls, so as to show such parts of their contained viscera as can then be seen lying in their natural position.

From the *thorax*, the sternum with parts of the nine upper ribs, their costal cartilages, and the greater part of the collar-bones are removed, together with the soft structures connected with them.

The mnscles of the front of the *neck* are also taken away to show certain parts which lie there, but belong to organs situate in the chest. These are

L The *Larynx*, or *organ of voice*, placed below the root of the tongue, upon the upper end of the windpipe.

T The *Trachea*, or *windpipe*, which forms the air-passage leading down into the chest to reach the lungs. Behind the larynx and trachea is seen the right side of the *Pharynx* and *Œsophagus* or *gullet*, the passages down which the food is swallowed.

At the sides of the chest, the cut surfaces of the ribs, of the thin intervening intercostal muscles, and of other muscles which lie upon them, are plainly shown. Along the lower margin of the thorax, the cartilages of the ribs RR, and the ensiform appendage of the sternum, are left untouched, in order to preserve the attachment of the diaphragm, which separates the chest from the abdomen, and part of the upper surface of which is seen, marked DD.

The muscular and tendinous walls of the *abdomen* are detached from the ribs above, and from the pubic bones, N, and Poupart's ligament (diagram No. 2, fig. 1, 47) below, where they join the fascia of the thighs; on each side of the body they are cut through, as shown by the surfaces, MM.

When thus opened, it is seen that the thorax or chest contains the *Lungs*, A, B, and the *Heart*, C,* that is, the great organs of *Respiration* and *Circulation;* whilst the abdomen is chiefly occupied by the principal organs of *Digestion*, of which only certain parts are here visible; viz., the liver, E, with the gall-bladder, G; the spleen, F; the stomach, S; the small intestines, II, and the large intestines KK. Part of the urinary bladder is also seen at J.

---

* The reader is requested to alter, with ink, the small c on the heart into a capital C.

The general position of these several viscera in regard to one another, and also to the surface of the body, can be learnt through the eye; but there are some points which require description.

In the Thorax.

A, B are the front surfaces of the right and left lungs, which are represented as if somewhat collapsed or shrunken, as always is the case when the chest is opened. Hence larger portions of the heart, C, and also of the diaphragm, DD, than are naturally in contact with the walls of the unopened chest, are exposed to view; for during life the lungs are not collapsed, their inner margins nearly overlap the heart, and their lower borders reach down to the rib cartilages, and accurately fit into the angle between these and the diaphragm.

The right lung, as here shown, is larger than the left, on which side the heart rather trespasses; it is marked off into three divisions or lobes, whilst the left has only two. The polygonal markings on the surface show certain small internal subdivisions of the lung-substance into parts called *lobules*. The upper lobe of the left lung is purposely turned aside to expose an additional portion of the heart, and of the sac or bag called the pericardium, P, in which it is placed, and which of course is here laid open. The two lungs are lodged in two distinct compartment of the chest, formed by two membranous sacs called the *Pleuræ*. Each membrane or *pleura*, thin and transparent, but tough and elastic, adheres closely, like a smooth lining, to the whole of the inside of the corresponding half of the thorax, but near the middle line of the chest, each passes from front to back, so as to partition off its own half from the rest, and thus forms a completely closed sac. In the figure, the two pleural sacs are opened by the removal of the front part of the pleuræ with the more solid parts of the thoracic walls; but the fine cut edges of each membrane are seen as it lines the ribs, the intercostal muscles, and the diaphragm, and also where it assists to form the twofold median partition just described,—especially on the right side of the chest.

Now the lungs project into these two compartments of the thorax, and are nearly everywhere *free*, being attached only at a comparatively small portion of their inner sides, by the great air-tubes, blood-vessels, and other smaller parts, which, together, form what are called their *roots*. Around and upon these roots, the membrane of the corresponding pleural sac is reflected from all sides on to the lung itself, and is thence prolonged all over it to its very edges, making its surface perfectly smooth, but showing the component lobules through.

The lung, therefore, though covered by the pleura, is really *outside the pleural sac*, the internal surfaces of which, smooth and moistened, one belonging to the lung and the other to the walls of the chest, are in contact with and glide easily on each other as required during the movements of respiration.

Between the right and left pleural sacs, just described, is a considerable interval, which is occupied principally by a third closed sac or bag, P, named the *Pericardium*, because it surrounds the heart. The pericardium is thicker and stronger, containing more fibrous tissue in its walls, than the pleuræ, with both of which it comes in contact. It also adheres to the diaphragm below.

In the figure, the pericardium, together with some of the left pleura adhering to it, is cut away to show part of the heart, C, and the commencement of some of the great blood-vessels, proceeding from the upper part or base of that organ. The inside of the pericardial sac is lined by a smooth and continually-moistened membrane, which is reflected on to the roots of the great blood-vessels by which the heart is attached above and behind, and is then prolonged over the heart itself; so that this organ, therefore, as is the case with the lungs in regard to the pleuræ, is really *outside* the closed sac.

This arrangement, by which an organ is adherent to one part of the outer surface of a closed and collapsed bag, whose cavity is obliterated by its inner surfaces being in contact, is the characteristic arrangement of a set of membranes, called *Serous Membranes*, to which class of structures, not only the pleuræ and pericardium, but several others belong. They are so named because the opposed surfaces are moistened with a thin fluid which was formerly likened to the serum or thin part of the blood. The use of such membranes is to insulate and facilitate the free movements of the organs which are covered by them,—the fluid, of course, serving to diminish the friction of the surfaces. Their microscopical structure is spoken of under diagram No. 9, fig. 71.

C shows a part only of the heart, the rest being concealed in the pericardium; nevertheless it can be perceived that its general position is between the lungs, but extending rather over into the left half of the chest. It is obvious, however, that in order to exhibit fully the shape and position of the heart, and its mode of attachment by means of the great blood-vessels issuing from or entering it, the lungs and the pericardium must be removed, as in diagram No. 4, fig. 1.

Those great vessels themselves must be reckoned as part of the contents of the cavity of the chest; and, besides these, as shown in diagram No. 6, fig. 14, the air-passage or windpipe, *t*, branching off for each lung, and the food-passage or gullet, *o*, leading from the throat to the stomach, *s*, lie partly within the thorax. Again, when these parts are removed, as in diagram No. 5, fig. 1, a large duct, *d*, called the *thoracic duct*, the use of which will be afterwards explained, is also seen to pass up through the chest, upon the vertebral column; and finally there are certain important nerves within the thorax, as shown and explained hereafter in diagram No. 7.

In the Abdomen.

The viscera of the abdomen, here only partially exposed, are very numerous. Such explanations as will enable the reader to understand their general position and connections will now be given, their special description being reserved for diagram No. 6.

E. A small portion of the upper surface of the *Liver*, appearing below the cartilages of the right ribs, and reaching across the pit of the stomach. The white oblique line seen upon it is the cut edge of the *broad ligament*, which helps to sustain the liver in its place. The liver is the organ which secretes the bile.

G. The anterior and larger end of the *Gall-bladder*, or receptacle for the bile, projecting from beneath the liver.

F. Small part of the lower end of the *Spleen* or *milt*, an organ the function of which is not well understood.

S. Part of the anterior surface of the *Stomach*, a membranous bag in which the food received from the gullet is detained for the purposes of digestion. It is here shown as if moderately distended.

This is, perhaps, the occasion, once for all, to explain that by anatomists the word "stomach" is never applied to the abdomen generally, as is commonly done when persons speak of having a pain in the stomach, or a stomach-ache, but always means the membranous bag, or dilated part of the digestive tube, marked S in the figure.

II. *Convolutions* or turns of the *Small Intestine*, also shown somewhat distended. It is the part of the alimentary canal through which the substances partly digested in the stomach pass after leaving that organ.

KK. A part of the *Large Intestine*, called the *Colon*, through which the residue of the digested food continues to pass. It is seen to surround the turns of the small intestine on three sides, *ascending* on the right side, passing *transversely* across just below the stomach, and *descending* again on the left side. It is here very slightly distended.

In the natural condition, it must here be noted, there exists a flat membrane, shaped like an apron, and usually containing much fat, which hangs down from the stomach and transverse part of the colon, and so conceals the convolutions of the small intestine. This is called the *Omentum*. It serves to fill up interspaces, to protect the intestines, and to maintain their temperature.

J. The upper part of the urinary bladder, which is for the most part contained within the pelvis.

The abdominal viscera just noticed are attached to the back of the abdomen by blood-vessels, nerves, and other soft parts. See diagrams Nos. 6 and 7, fig. 1. Moreover, they are closely covered by a thin serous membrane called the *Peritonæum*, which forms one of their coats, and which, being reflected at the point of attachment of the various organs on to the walls of the abdominal cavity, which it lines throughout, also serves as a means of holding the various parts in their places. This, in fact, like other serous membranes, is so arranged as to form a closed and collapsed sac, having the viscera outside it, helping to support them, and facilitating their various movements.

The remaining abdominal organs, to be seen only on removing the parts shown in this figure, are as follows:—the *Pancreas*, a glandular organ necessary to digestion, represented in diagram No. 6, fig. 17, *b;* the commencement of the *Thoracic Duct*, diagram No. 5, fig. 1, *r;* the right and left *Kidneys* and *Suprarenal Capsules*, with the *Ureters* or tubes leading to the bladder, shown on the left side, in diagram No. 4, fig. 1,—*g* being the kidney, *f*, its ureter, and *t*, the bladder; and lastly, numerous large vessels and nerves to be hereafter described. Taking now a last general glance, in this diagram, at the thoracic and abdominal viscera, as they lie within the trunk, the former devoted to respiration and circulation, the latter principally to the processes of digestion, it is impossible not to be struck with the twofold conviction of the importance of allowing all those organs their natural space and freedom of action, and of the mischievous influences of tight-lacing. In the case of persons who have long followed that bad practice, the lower part of the thorax, naturally the widest, is made almost the narrowest, the lungs and heart are compressed and displaced, whilst the liver and stomach have been found forced downwards almost as low as the pelvis. The serious interference of all this with the functions of these parts, especially with those of the lungs and heart, will be still more evident when the movements necessary to easy and perfect respiration and circulation have been described.

Figures 1 to 9.

Organs of Respiration; the Lungs, Air-tubes, and other apparatus of the respiratory movements.

In the respiration or breathing of animals two essential and associated phenomena occur; viz., the absorption or passage of *oxygen* gas into the living system, and the evolution or escape of *carbonic acid* gas from it. Expressed generally, the result of the respiratory process is the oxygenation or chemical union of oxygen with the materials of the whole body; but two important consequences, especially observable in the higher animals, are dependent upon it; namely, first, the continuous purification of the nutritive circulating fluid or blood, to fit it for maintaining in an active and healthy condition all the living tissues; and secondly, the unceasing development of more or less animal heat. The functional power of any animal, and the natural temperature of its body, are therefore in general accord with the activity of its respiration.

Some animals respire only through water, and others only in the air, obtaining the oxygen necessary for their respiration from one or other of those two media; and, according as the respiratory interchange of that gas with the carbonic acid thrown out, takes place through water or through air, the respiration is said to be *aquatic* or *aërial.*

Amongst the vertebrate animals, fishes are aquatic breathers, the respiratory function in them being performed by means of those well-known red, fringe-like, highly vascular, covered appendages, called *branchiæ* or *gills.* Through these the blood of the creature is passed along small tubes called blood-vessels in minutely-divided streams, which come near enough to the water for the interchange of the oxygen and carbonic acid in solution or combination in those fluids to take place through the delicate coats of the finest blood-vessels. Certain fishes possess in the interior of their body, just beneath the back-bone, an elongated sac or bladder, called the *air-bladder* or *sound,* which is, in most cases, completely closed and shut off from all communication with other passages or canals. In a few species, however, it communicates with the upper part of the digestive canal, but it is not certain that even then it has any respiratory office, unless indeed as one entirely complimentary to that of the gills. It appears to be used by those fishes which possess it, as a means of altering their specific gravity in water, either by a rapid secretion or absorption of its contained air. This air-bladder of the fish is nevertheless a highly interesting organ, as the earliest anatomical representative of the respiratory apparatus of animals higher in the scale, viz., the batrachians or frog- and newt-class, reptiles, birds, and mammalia including man,—all of which breathe air by means of internal air-sacs, which might be regarded as complex and highly organized *air-bladders,* communicating through the throat with the external atmosphere, and designated *lungs.* The presence of the air-bladder in fishes affords us a good illustration of the general fact, so frequently met with in comparative anatomy, of certain organs, of the highest importance in some classes, being present in a very rudimentary state, and perhaps sometimes without any special function, in another class,—betokening rather by their silent but impressive testimony the grand unity and comprehensiveness of the primitive creative thought. In the batrachians, that curious and truly amphibious class intermediate between fishes and reptiles, represented in our own country by the newts, toads, and frogs, respiration is performed during their *young state* in water, first by external, and then by internal concealed or covered gills; but in their *perfect condition* they acquire lungs, which commence as off-shoots, like the fish's most developed air-bladder, from the upper part of the digestive canal, and then they breathe air. Some, as the proteus and siren, singularly enough, retain their gills throughout life, thus breathing in both ways; but the greater number, as newts, frogs, and toads, ultimately lose those organs and breathe henceforth by lungs only.

The simplest known form of lungs is a pair of elastic membranous bags, placed in the interior of the body, close beneath the vertebral column, and communicating with the surrounding atmosphere by means of a common tube, which opens above by a single orifice into the throat. Upon the walls of these inflated bags is a network of minute blood-vessels, through which all the blood in the animal's body is in turn driven by the heart. A delicate moist transparent membrane, called a *Mucous Membrane,* lines the bags throughout, closely covers the vascular network, and *alone* separates this from the air within the sac. Being exceedingly thin, and always moist, this membrane absorbs, after dissolving, the oxygen of the air, and thus enables it to pass into the moving current of blood; whilst through the same means, but in the opposite direction, carbonic acid simultaneously escapes from the blood into the air. To complete this apparatus, certain vital mechanical contrivances, set in motion by muscles and regulated by the nervous system, empty the bags at intervals of the impure air and refill them with fresh air, and so insure the continuance of the respiratory process. Such simple sac-like bags as these exist in the gilled proteus above mentioned,—a creature which inhabits the dark pools of certain mountain caverns.

The structural alterations and additions by which such simple respiratory sacs are modified, so as to suit the wants of more highly-organized animals, may be arranged under three heads, according to the objects which are aimed at.

First, contrivances by which the internal surface of the lungs may be increased and complicated, so as to enlarge the actual area covered by the vascular network, and at the same time more minutely subdivide the air.

Secondly, arrangements for the more frequent and regular change of the contained air.

Thirdly, certain modifications in the blood-vessels or circulatory apparatus, intended to increase the quantity of blood sent to the lungs in a given time, and also its degree of subdivision into minute streams and its freedom of exposure to the influence of the air.

Fourthly, beyond these structural or anatomical modifications, it must also be observed that the efficiency of any given respiratory apparatus is greatly influenced by various physiological and chemico-vital conditions, to which our attention must, in the last place, be directed.

1. Mode of obtaining an increased area for the vascular network of the lungs, and the minute subdivision of the contained air.

It is sufficiently obvious that the first of these objects alone might easily be obtained by increasing the size of the lung-sacs themselves; but as that could only be done within certain limits, dependent on the size of the animal, two other plans are followed, each of which fulfils both of the objects set forth at the head of this paragraph. According to the one plan, the internal surface of the sacs is moulded into numerous depressions or cells, separated by thin ridges or projecting partitions, somewhat like the cells of a honeycomb, and having the blood-vessels spread over every part; according to the other, and far more efficient plan, vast multitudes of little lung-sacs, having a highly complicated cellular interior, are clustered around the ultimate branches of a common tube, which supplies air to them all. By the first method the lung-sacs are simply rendered more and more *cellular* in their interior, as shown in the lungs of the colded-blooded serpents, frogs, and turtles, illustrated in figs. 6, 7, and 8 of the present diagram; whilst on the second plan, *compound lungs* are formed, such as exist in the warm-blooded birds and mammalia, and are illustrated in the human lung, the structure of which is represented in figs. 1, 2, 3, and 9.

These diagrammatic representations may now be studied.

Fig. 6 is an enlarged plan, showing a section of the upper and lower ends of the right lung of a serpent, the middle part being omitted for convenience of space. In most serpents the right lung only is fully developed, that of the left side being small or absent. In this figure, by an accidental error, the portion shown of the left lung is represented as wide as the right lung.

The lung-sac of the serpent is of great length, but its respiratory surface is principally increased by the cellular formation existing at its upper portion, where the blood-vessels chiefly abound, the lower remaining part being smooth and less vascular.

Fig. 7, more highly magnified than fig. 6, is a section-plan of the frog's lungs, which have the cellular spaces already spoken of, uniformly developed over their entire inner surface.

Fig. 8, also a section-plan, shows one of the lungs of a turtle, in which a still more complicated cellular arrangements prevails throughout; the cells being wide and deep, and collected into groups, between which are deeper but still incomplete partitions, themselves also covered with cells. Viewed generally, such a lung may be said to have one irregularly branching central cavity with which all the cells more or less directly communicate. The increase of surface here obtained is very obvious, so that the area for the vascular network is enlarged, and the air in the lungs is more subdivided than in the simple form of lung-sac.

In the frog, serpent, and turtle, and in all allied creatures, the main air-tube, or *windpipe*, which leads from the throat to the lungs, ends below by dividing into two tubes, called *Bronchi*, each of which opens at once into the corresponding lung-sac, right or left, without distinctly penetrating by branches into its interior. In serpents, with only one developed lung, there is only one developed bronchus. The ramified central cavity in the turtle's lungs, which, we may observe, is still more evidently marked in the lungs of the crocodile, is the first step towards that distinct ramification of the air-tubes or bronchi within those organs, which we have next to describe as an essential condition of the more highly organized compound lungs proper to the warm-blooded animals and man.

These we shall illustrate by reference to the structure of the human lungs.

Fig. 2 is a shaded diagram to show the ramification of the air-tubes in the human lungs. L is an outline representing the left lung; T, the main air-tube, called the windpipe or trachea, which, as shown in fig. 1, descends through the neck, from the larynx or organ of voice, L, into the chest. (Compare also fig. 14, diagram No. 6, in which the trachea is marked *t*, and fig. 3, in the same diagram, which shows a section through the trachea.)

B shows the right and left bronchi, into which the windpipe divides, one for each lung. Each bronchus enters the lung at the root, which it helps to form, and then divides and subdivides, as further shown in fig. 3 of the present diagram, into smaller and smaller tubes, which do not unite or coalesce again, but continue separate, after the manner of the branches and twigs of a tree. These tubes are called *bronchiæ* or *bronchial tubes;* the smallest shown in this diagram *bb*, undergo many further subdivisions, until, at length, they form an immense number of minute tubes, not more than $\frac{1}{70}$th of an inch in diameter, each of which ends in a cluster of cells, or, as it may otherwise be described, opens into a small membranous sac, a little wider than itself, having a cellular internal surface, very similar to that of the frog's lung, but of course on a microscopic scale.

Fig. 9 is an enlarged diagram of three of these clusters of cells or little lung-sacs from the human lung; it is magnified about 100 diameters; *b* is a small air-tube or bronchial tube, from which several of the finest or ultimate tubes proceed; *c* shows the outer surface of one lung-sac; and *d*, the inner surface of another, studded with little pouches or cells, which are called the *air-cells* or *air-vesicles*, and are the ultimate recesses to which the minutely subdivided air gains access. They measure from $\frac{1}{200}$th to $\frac{1}{70}$th of an inch across, and it is on the inner surface of the walls and partitions of these that the network of fine blood-vessels is spread out. For the most part, the air-cells of adjacent little lung-sacs do not communicate with each other, excepting through the finest bronchial tubules, but occasionally direct communications may exist by thinning of the intermediate walls. These cellular lung-sacs are grouped together in small masses, or independent portions of lung, called *lobules*, each of which has its own principal bronchial tube entering it and branching out for its component lung-sacs. Everywhere these lobules are compressed at their sides, so as accurately to fit against each other, and are held together by intermediate connective tissue. In the interior of the lungs, they are not easy to show separately, but on the surface, as in fig. 1, A and B, they are plainly indicated by little polygonal markings. The air-cells of adjacent lobules never communicate directly; but on cutting across a piece of lung, they may be seen laid open at all points of the cut surface, clustered around the air-tubes which appear on the section as rounded openings. It is calculated that there are not fewer than 600 millions of air-cells in the two adult human lungs, so great is the subdivision of the air contained in the interior of these organs. Owing to the presence of this included air, the substance of the lungs (as may be easily exhibited in the lung of the calf, which can be procured and examined to illustrate many points in the present description) has a soft spongy feel, and creeks when it is compressed between the fingers. Hence, too, the lungs float in water, and even small pieces cut out and squeezed violently, still retain sufficient air in their vesicular structure to make them buoyant. During life, when well expanded, the lungs containing more air, their air-cells are larger than in the dead and collapsed lung, which may, therefore, by gently blowing into the windpipe, be again distended and then suffered to collapse.

The total quantity of air, after a deep inspiration, in the chest of a healthy adult man of average height is about 330 cubic inches; of this, 220 cubic inches can be forcibly expired, leaving 110 cubic inches in the lungs. After an ordinary expiration, about 170 cubic inches are retained, and about 20 cubic inches would measure the amount of displacement of air which takes place in ordinary expiration and inspiration. The quantity retained, with a moderate effort, is sufficient to make the whole mass of the human body rather lighter than water; so that a person immersed in that element, who retains his self-command, and keeps the mouth and nose upwards and the arms beneath the surface, will not sink, although doubtless he will rise and fall in the water, as he fills and empties the lungs in the necessary act of breathing.

The lungs of quadrupeds and monkeys are similar in general structure to those of man, but their shape varies in different animals according to the form of their thorax. The lungs of slaughtered animals are vulgarly called "the lights," doubtless from their lightness, as compared with other viscera of the body. They are usually of a pale pinkish colour, and this is also the case in the human infant and child; but in the adult, both human and animal, they become variously mottled with black, pink, and a mixture of the two hues forming a sort of bluish purple. The black colour is owing to the deposit of animal matter called pigment.

In birds, whose respiration is more active, and whose temperature is higher than that of quadrupeds, monkeys, or man, and in which creatures also, as the most perfectly organized for flight, a necessity exists for reducing their specific gravity to the utmost, some interesting peculiarities of structure are observed. In the first place, the air-cells are, speaking generally, smaller than in the mammalia including man, and, moreover, they communicate directly with one another, like the interspaces in a sponge; so that the air is not only subjected to the utmost possible amount of subdivision, but the intermediate cell-walls, with their networks of blood-vessels, are often submitted to the contact of the air on both sides, instead of on their inner side only, as in the mammalian lung. Moreover, by a most remarkable provision, evidently intended to lighten the weight of those animals, and especially noticeable in birds of great power of flight, some of the bronchial tubes pass quite through to the surface of the lungs, and there open into membranous passages which lead to *air-chambers* placed in certain parts of the body, as in the abdomen and in the interior of many of the bones, especially of the long bones.

The *structure* of the walls of the air-tubes and air-cells is a subject of much interest, and must not escape notice here.

In the simple sac-like lungs of the proteus, and others, the walls are composed essentially of an outer membrane or coat, consisting of areolar or connective tissue mixed with much yellow elastic tissue, and of an inner coat or lining formed of the vascular mucous membrane. In the cellular lungs, like the frog's, the chief partitions are merely stronger and thicker than the secondary ones. In the lung of the serpent and turtle, slips of cartilage are for the first time introduced to strengthen and keep open the principal intercellular septa and the margins of the larger communicating openings of the irregularly branched central cavity. In birds, mammalia, and man, the walls of the *air-cells* are composed of areolar mixed with fine elastic tissue, and are lined by an exceedingly delicate mucous coat, composed of a thin transparent basement membrane covered with a squamous non-ciliated epithelium. See the explanations under diagram No. 9.

As to the structure of the main *air-tube* or windpipe, which leads from the throat down to the lungs, it is, in the proteus, which relies on gills as well as on air-breathing organs, simply a membranous tube opening above into the throat by a mere slit unguarded by any cartilaginous structure. In examining, however, the windpipe or trachea of the salamander, frog, lizard, serpent, and turtle, and also the trachea and bronchial tubes of birds and mammalia, there is found a gradual super-addition of certain specially formed and admirably contrived cartilaginous rings or pieces in certain parts of their walls, the principal object of which is to insure the constantly pervious state of the air-passages under the varied conditions to which they are subjected. A few of these cartilaginous pieces, placed upon the upper end of the windpipe, next the throat, form, as we trace them in the ascending scale of the animals just mentioned, the basis of a more and more complex apparatus, called the *Larynx*, which, provided with fit muscles and nerves, not only guards the entrance of the air-passages against the introduction of food or drink, but also forms that most wonderfully constructed and endowed organ, by which the voice of animals and man is produced.

In the human body, the opening of the great air-passage is placed beyond the back of the tongue, and leads from the lower and fore part of the pharynx, as shown in diagram No. 6, figs. 3 and 4, where *t* is the trachea, *l* the larynx, *p* the pharynx, and *e* a cartilaginous flap named the *Epiglottis*, guarding the opening called the *Glottis*, which leads into the larynx. The structure of the air-tubes below the larynx is illustrated in figs. 2, 3, and 4 of the present diagram. The walls of these tubes are essentially membranous, being thicker in the larger tubes, and gradually becoming thinner as these divide and subdivide, until they become continuous at the extremities of the finest bronchial tubes with the thin transparent sides of the air-cells. This membrane consists, first, of an outer fibrous coat formed of dense areolar tissue and much interwoven elastic tissue; many independent bundles of the latter also run longitudinally in the tubes. There is, secondly, an inner lining coat, or mucous membrane, which, as if to keep the mucus moving over the surface, is provided with the little organs called cilia (see diagram No. 9, figs. 79 and 81), and is ultimately continuous with the non-ciliated mucous membrane of the air-cells. In the trachea and larger bronchial tubes are many mucous glands opening upon the surface. Imbedded in the fibrous coat are the cartilaginous pieces already alluded to, of various shapes and sizes in different parts of the air-tubes.

In the trachea, fig. 2 T, these cartilaginous pieces, about twenty in number, form a series of little transverse or horizontal flattened strips or bands, incomplete behind; so that each is shaped like the letter C, with its open part turned backwards. Owing to the presence of these *rings*, as they are called, the trachea is rough or uneven in front and at the sides; hence its name, from the Greek τραχὺς (*trachus*), rough.

In fig. 4, which is a section of part of the trachea much enlarged, *r* is one of these cartilaginous rings. It is also shown that at the back part of the tube the membrane being unsupported, as the ring is there absent, is flattened. This part, moreover, contains numerous transverse *involuntary* muscular fibres, which pass from one side to the other, and serve in action to narrow the calibre of the tube. It also lodges in its substance many little mucous glands.

In fig. 3, which is a posterior diagrammatic view of the air-tubes and the lungs and heart, with the great blood-vessels passing from the one to the other, the trachea is marked T; the left lung, dissected to show the air-tubes and blood-vessels branching within it, and the right lung only partially sketched out, are marked LL; the heart is indicated by the letter H. Of the two primary divisions of the trachea named the bronchi, the left one is marked *b*. The flatness of the trachea behind is here displayed,—the tips of its rings being seen at either border. The two bronchi, though of smaller size, have a similar structure to the trachea itself, being provided with incomplete cartilaginous rings in front (see fig. 2), but being only membranous and muscular behind, fig. 3. From the peculiar structure just described, the trachea can be bent, compressed, or twisted during the movements of the neck, without its canal being closed. The open condition of its rings behind offers less resistance to the passage of food as it is being swallowed down the œsophagus or gullet, which, as seen in diagram No. 6, figs. 3, 4, and 14, *o*, descends in close contact with the back part of the trachea, *t*. Lastly, it is obvious that the entire arrangement of the membranous and cartilaginous structures, the longitudinal elastic, and transverse muscular fibres of the trachea and the two bronchi, is well calculated to facilitate such changes as may be necessary in the length and diameter, and in the degree of tension of the walls of those tubes.

On entering the lungs, the air-tubes cease to be provided with regular transverse slips of cartilage, but instead of this are beset with angular or polygonal plates of that substance, placed at all sides of the bronchiæ, and corresponding in size with them. Little spur-shaped pieces usually exist at the angles of bifurcation of the various tubes, and minute flakes of cartilage are found even in the smaller bronchiæ; but the very smallest are entirely membranous. Down to the very smallest, too, all these tubes are provided with longitudinal bands of elastic tissue and circular muscular fibres of the involuntary kind, which enable them to be narrowed, elongated, or shortened, according as the lung is full or empty of air. The air-cells themselves also, containing in their walls much elastic tissue, easily accommodate themselves to the varying quantities of air which they at different times contain; and in the interlobular connective tissue and pleural coat of the whole lung, there is also much elastic tissue, which co-operates in producing the general resiliency of the entire organ. The use of the cartilaginous plates in the membranous walls of the tubes is evidently, by their resistance, to preserve the whole series of larger and smaller air-passages permanently open and pervious to air. Especially are they needed to prevent closure of the bronchiæ during the escape of the air in expiration, when the rest of the lung substance is everywhere collapsing around those tubes; but in inspiration, they are also useful in giving straightness to the tubes and facility of expansion to their walls.

The combined sectional area of the smaller air-tubes is greater than that of the larger ones, and far greater than that of the trachea. Hence, as the stream of air enters the lungs in inspiration, its rate of motion is gradually diminished as it approaches the air-cells,—a provision suitable for the safety of the walls of those little cells, and for their delicate capillary network. On the other hand, as the air passes out again, its rate of movement is progressively quickened, and so it is driven more readily away from the chance of being again inhaled, and acquires sufficient velocity to be made available for the production of voice and speech.

2. We have now to consider the various modes in which, in different animals and in man, the ingress and egress of air into and out of the lungs are more or less regularly and frequently accomplished,—in other words, the mechanism of *inspiration*, or breathing air in, and of *expiration*, or breathing it out again.

In the proteus, salamander, and frog, the ribs are either wanting, or are so little developed that there is no distinct thorax. In the case of such animals, the jaws being first closed, air is drawn through the nostrils into the mouth by the descent of the tongue and other parts forming the floor of that cavity, and is then forced down into the windpipe by the ascent of the same parts,—both movements being performed by muscles attached to the bony or cartilaginous apparatus, which, in these creatures, supports the tongue.

The portion of air thus pumped into the lungs having been retained there some time, is then expelled, usually through the open mouth, and chiefly by means of the resiliency of the elastic tissue of the lungs themselves, aided, however by the contraction of the abdominal muscles. In the turtles and tortoises, in which animals the ribs, though largely developed, are fixed and consolidated in the formation of their protecting case, the air is also forced or pumped down into the lungs, and afterwards driven out in a similar way to that just described, though at more regular and frequent intervals.

In serpents, the ribs, though of considerable length, are not joined along the front or under-side of the body to a sternum or breast-bone, so that the long framework of the thorax is incomplete in that direction; but the ribs being very movable, are drawn apart laterally by proper muscles, so as to enlarge the part of the body which contains the lungs; and thus pressure being removed from the outer surface of those organs, air rushes into them through the windpipe. The expulsion of the air in expiration is due partly to the elasticity of the lungs themselves, partly to the passive recoil of the ribs, and partly, also, to the compression exercised by the muscles attached to those bones and by the contraction of the abdominal muscles.

In lizards and crocodiles, the thoracic framework is completed underneath by a sternum to which a variable number of the ribs is attached, and the alternate expansion and collapse of the thoracic cavity and of its contained lungs are effected in a similar but more perfect manner than in the case of the incomplete thorax of the serpent tribe.

In birds, the bony thorax is also complete, but the sternum is so large and specially constructed as a basis for the strong muscles of flight, that the cavity of the trunk cannot be dilated so freely in the lateral direction as it can be from back to front. The movements of ordinary inspiration and expiration are here performed in a very peculiar manner, reversing, so far as active effort is concerned, the methods hitherto noticed; for it would seem that it is during expiration that the principal muscular effort is made, the sternum being then drawn up by muscles towards the back of the animal, so as to cause compression of the lungs; whereas, in inspiration, those muscles relax, and the sternum springing downwards, the lungs are relieved from pressure, and immediately fresh air is allowed to enter them through the windpipe. In all the cases yet mentioned, viz. in the batrachia, reptiles, and birds, the thorax and abdomen form a single cavity, called the thoracico-abdominal cavity, the chest not being shut off from the part containing the digestive organs by a transverse partition or diaphragm.

The rudiments of such a structure, however, do exist in the higher reptiles and in birds, in which animals a muscular structure spreads out from the back-bone on to the hinder part of the lungs, and by its contraction draws upon, and so helps to expand, those organs.

In all mammalia, as in man, the thorax and abdomen are completely separated by the musculo-tendinous partition called the diaphragm, already described (p. 29), and the mechanism of their respiration is modified accordingly. The following account of it refers particularly to the human body, but is generally applicable to all the mammalia.

The lungs, it will be remembered, are suspended in the chest by their attached parts or roots situated on their inner side, and are free at all other points. When the thorax is opened, as shown and already explained in fig. 1 of this diagram, the lungs shrink back towards their roots, a certain portion of their contained air being driven out of them through the trachea, so that they no longer touch the sides of the chest; but it is very important to bear in mind that in the yet unopened thorax (therefore, during life), the lungs are in close contact with the inner surface of the walls of that cavity. Under the first-named condition the lungs collapse, because the atmospheric pressure on their surface, and that in the interior of their air-tubes and cells being exactly balanced and equally exercised, the elasticity of the pulmonary tissues comes into play; whereas, in the unopened chest, the resistance offered by the strong thoracic walls interferes with the equilibrium of the external and internal atmospheric pressure, by supporting or bearing off that which would otherwise operate on the surface of the lungs; and so the excess of pressure in the interior of those organs resists the elastic force of their tissues, which gives them a constant tendency to collapse. At the end of a forced expiration during life, this is precisely the condition of the parts; but when we again inspire, the walls of the chest actively expand, so as to increase the dimensions of the cavity in length, breadth, and depth.

During the act of expansion, the effect of atmospheric pressure on the surface of the lungs is progressively diminished, whilst that in their interior remains unchanged: fresh air accordingly enters rapidly through the windpipe, the elasticity of the lungs is overpowered, and they become so distended as to keep in perfect contact with the inner surface of the thoracic cavity. When inspiration is completed, the chest again falls in or subsides, and the lungs are once more partially emptied of air, still, however, preserving their constant condition of contact with the thoracic walls. From this account it will be seen, that, excepting in so much as depends on the elasticity of their tissues, the lungs are mechanically passive in inspiration and expiration, but strictly obey or follow the movements of the thorax itself; and for this purpose, the most admirable provision is made in their free suspension in the chest, and in the arrangement of the pleuræ, already described (p. 31), which is only found, in perfection, in conjunction with a diaphragm.

It remains now to examine by what means the cavity of the thorax is alternately enlarged and diminished in the three directions of its depth, breadth, and length. For understanding this, a reference to fig. 5 is indispensable. VV is the vertebral column; S, side of the sacrum; C, section of pubes; A, cavity of abdomen; T, cavity of thorax; B, sternum or breast-bone; D, the diaphragm. The dorsal part of the vertebral column, V, may be regarded as the comparatively immovable basis on which the respiratory movements of other parts of the chest are performed. The sternum, B, again, is not acted upon directly by muscles, so as to manifest any well-marked movements on the ribs, but rather is moved indirectly through or lifted by the ribs. The principal and, indeed, essential movements take place in the ribs themselves, in their costal cartilages, and in the vaulted diaphragm, D.

Now, in the first place, the upper rib is on each side placed nearly horizontally, and possesses only a very slight freedom of movement; but the succeeding ribs are directed more and more obliquely downwards and forwards from their points of attachment at the dorsal vertebræ, and are very much more movable on the vertebral column. Suppose, then, the first rib on each side to be fixed, and all those below them which are connected directly or indirectly with the sternum, to be raised by a general movement from the oblique to a nearly horizontal direction, it is obvious that the horizontal distance between the anterior extremities or tips of their costal cartilages and the vertical line of the back-bone must be everywhere increased, and that the sternum, B, must be lifted upward and forward. In this manner it is that the chest is enlarged from back to front, that is, in *depth.*

Again, as the ribs are more or less strongly curved at the sides of the chest and individually move upon their two extremities as fulcra of support, it follows, that in being drawn upwards, besides undergoing the general elevation just described, each undergoes a slight twisting movement, which throws its outer surface a little upwards, and its lower border a little outwards. This twisting movement, moreover, is particularly and beautifully favoured by the elasticity of ths costal cartilages, which yield more rapidly than bone; and the total effect on all the ribs is to lift them outwards or sideways from the median plane of the thorax, and thus to enlarge its lateral dimensions or *width*.

In this way, also, the space between the ribs, below the third, are, for the most part, widened, particularly at the fore-part of the sides of the chest. The muscles concerned in producing the movements of the ribs, which thus enlarge the thorax in depth and width, are the external intercostals, the levators of the ribs, and part of the internal intercostals. (See diagram No. 5, fig. 1.) The first ribs are raised and fixed by muscles in the neck.

Finally, the enlargement of the thoracic cavity in *length*, though partly due to the increased convexity of its anterior surface, and partly dependent on the slight raising of the upper ribs and the somewhat more marked depression of the lower or floating ribs which do not reach the sternum, is more especially accomplished by the descent of the diaphragm, D. The contraction of the muscular portion of this movable vaulted floor draws down the central tendinous part, diminishes its curvature, and so increases the thoracic cavity in length. In this movement, the abdominal viscera are of course slightly thrust downwards, and the yielding abdominal walls protrude (see the fig. 5). Hence any costume fitting too closely around the abdomen decidedly interferes with easy respiration, though not quite so much as if it were around the ribs themselves; and thus, even long-waisted dresses should not be girded too tightly.

The movements of the chest during expiration are just the reverse of those determined by the inspiratory effort. The diaphragm now ascends, the abdominal viscera follow it, and the walls of the abdomen again recede; the ribs fall downwards and inwards at the sides and in front and approach each other, and the sternum sinks. The position of the sternum, B, and diaphragm, D, at the end of an expiration is shown by the dotted or interrupted red lines. During ordinary breathing, these several expiratory movements do not demand the same amount of active muscular effort as those of inspiration. They chiefly depend upon the recoil of the thoracic walls, which takes place on the cessation of action in the various muscles by which they had previously been expanded. Thus, the diaphragm relaxes, and is carried up by the pressure and tension of the walls of the abdomen acting upon the abdominal viscera. The muscles, which, in lifting and widening out the ribs during inspiration, had twisted the costal cartilages, and put the costal ligaments on the stretch, also relax; and the liberated weight and tension of all those parts, and especially the reaction of the costal cartilages, whose elasticity here comes beautifully into play, cause the movable bars of the thoracic cage again to subside, and the sternum to sink back. There are, however, a few muscles, viz. part of the internal layer of intercostals, and also, in a slight degree, the muscles of the abdomen, which co-operate in the expiratory movements; and doubtless, in regulating or arresting at any point the movements of inspiration, they are constantly more or less employed. That the mere mechanical recoil of the thoracic walls and the passive ascent of the diaphragm, co-operating with the elastic force of the tissue of the lungs, are efficient causes of emptying the chest, is shown by the fact, that at the cessation of life, the last movement of the thorax, by which its walls assume a state of physical equilibrium and finally repose to expand no more, is one of deep expiration, and hence it is, that to expire is, in a figurative sense, synonymous with to die.

In the forced or laboured respiratory movements, rendered necessary by exercise, effort, or disease, many more muscles, besides the diaphragm, intercostals, and levators of the ribs, are brought into play, especially all the muscles of the trunk or neck which have any attachment to the ribs or sternum. Such are the serratus, diagram No. 2, fig. 1, 21; the latissimus dorsi, 20; the pectorals, 18; the sterno-mastoid, 15; the muscles of the abdomen, 45; and others, not shown in that figure;—some of them acting in forcible inspiration, and others in forcible expiration.

Finally, if we take also into account, that during the distressing paroxysms of an attack of asthma, the limbs, head, and trunk are themselves held by their own proper muscles in certain fixed positions, from which the muscles attached to the thorax can act; and, moreover, that even the features of the sufferer testify, by their painful expression, the sympathetic action of the muscles of the face,—it will be readily understood, that in extreme commotions of the respiratory function, every muscle of the body may, in its turn, be employed. Even in the gentlest respiration, as in sleep, there is a sympathetic movement of the nostrils.

The act of inspiration, and the subsequent act of expiration, constitute a complete respiratory act, which in man is repeated, on an average, about eighteen times in a minute. But besides these rhythmical movements, which may themselves vary in frequency and depth according to the necessities of the individual for inhaling fresh air, there are many other kinds of movements, of which the respiratory apparatus is the principal seat.

Thus, sighing consists of a slow and full inspiration, followed by an equally prolonged expiration. Yawning or gaping is much the same kind of act, but of greater force, longer maintained, and accompanied by the well-known action of the muscles, which depress the lower jaw and tongue. Laughing is a series of short, sudden, jerking expirations, associated with various movements in the muscles of the face and body. It is singular that the movements of crying are very similar to those of laughter; and it is proverbial, that it is by no means difficult to laugh until we cry. In sobbing, a series of convulsive contractions of the diaphragm takes place; but the air-passage is closed above at the larynx, so that no air can get in. In hiccough, the same action of the diaphragm is seen, and the air-passages, at first opened, are suddenly closed at intervals, so as to produce the characteristic catching of the breath. Sneezing consists of a comparatively long inspiration, suddenly interrupted and followed by a short forcible expiration,—the breath being driven chiefly through the nose so as to expel irritant substances, but passing also partly through the mouth. Coughing consists of long preparatory inspirations to fill the lungs, and then of a series of short interrupted expirations, the air being expelled entirely through the mouth,—the necessary interruption to its escape at intervals being effected by sudden spasm or closure of the upper part of the air-passages in the larynx, as any one may experience for himself. Voice and speech likewise require respiratory efforts to supply the necessary column of air to be moved through the larynx. Lastly, the thorax is much used in bodily efforts of various kinds. It is the basis of support for the upper limbs, and to render it more fixed and solid, it is often fully expanded; the air is retained in it by complete closure of the upper aperture of the larynx, and is compressed by an expiratory effort. As any one may easily realise on experiment, a much greater force can be exerted when the chest is thus prepared, than if it be empty, or the aperture leading into the windpipe be open. This is a good example of the exercise of the will over muscles, which usually act involuntarily. It is, in fact, as in name, holding the breath. By this act we arrest the thoracic movements; but soon we are compelled to yield again to the necessity of breathing, or, as it is commonly expressed, the want of breath. All the ordinary and applied respiratory movements can be imitated at pleasure, even those which are usually involuntary; but whether these be essential to life, instinctive, emotional, or the result of will, they are all under the control of the nervous system, as we shall see hereafter, in describing diagram No. 7.

3. The modifications of the general circulatory apparatus in different animals, whether aquatic or aërial breathers, which influence the quantity of blood sent to the respiratory organs in a given time, will be best examined in connection with the succeeding diagram, which is especially devoted to the Organs of the Circulation; but such contrivances as determine the subdivision of the blood into minute streams, and its relative exposure to the action of the atmosphere in air-breathing creatures, may be here described.

In all cases, the blood is sent to the lungs by the heart, a hollow mnscular organ, which, contracting on its contained blood, forces some of it along certain tubes or vessels called *arteries*, those proper to the lungs being named the *pulmonary arteries* (from *pulmo*, a lung). These arteries, after branching many times, end at last in a fine microscopic network composed of vessels called, from their fineness, *capillaries* (from *capillus*, a hair, though they are much finer than hairs). From these *pulmonary capillaries* minute twigs of another set of vessels arise, called *veins*, which, uniting into larger and larger branches, form the *pulmonary veins*, by which the blood is conveyed back to the heart again.

In man, the anatomy of these parts is illustrated in fig. 3 of the present diagram.

Fig. 3 shows the heart, and the great blood-vessels leading into and out of the left lung, as viewed from behind. The trachea, bronchi, and lungs have already been described. The *left division of the pulmonary artery*, coloured blue, and marked *a*, conveys dark-red deteriorated blood from the heart to the left lung; and the *two left pulmonary veins*, coloured red, and marked *v*, *v*, bring the bright-red renovated blood back to the heart again. The principal branches of these two kinds of vessels are seen dividing and subdividing within the dissected lung, in company with the successive ramifications of the bronchial tubes. The same arrangements of course exist in the right lung. The finest arteries and veins could not be here shown, as their subdivision proceeds till they are no longer visible, except by aid of a microscope. The intermediate capillary network is placed on the walls of the multitudinous little air-cells; its component vessels are extremely fine, being, on an average, about $\frac{1}{3000}$th of an inch in diameter, and they are so crowded, that the meshes which they form are hardly wider than the vessels themselves. They are shown in diagram No. 9, fig. 63. The blood strained through this vascular network in such minute streamlets is separated from the highly-divided atmosphere of the air-cells by nothing but the delicate transparent walls of the capillaries, and the equally delicate lining membrane of the air-cells. Here it is that the gases of the blood and of the air are freely interchanged, carbonic acid passing out and oxygen passing in, and the blood, from being dark and deteriorated, becoming revivified and scarlet. Some of the nitrogen of the atmosphere (which consists of four volumes of that gas to one of oxygen) is also probably absorbed, and its place taken by nitrogen exhaled from the blood itself, its quantity in the expired air being, on the whole, very slightly increased.

This interchange of carbonic acid and oxygen in the lungs presents two different stages, which respectively appear to have some relation, in a mere physical point of view, to the interesting process of the *diffusion of gases* in a *dry* state, and to their manner of passing through *moist* membranes. When two dry gases are placed carefully in contact, without agitation, in a glass apparatus, they have an immediate tendency to mix or diffuse one into the other,—this diffusive property being so strong that it overcomes the effect of gravity, for a heavy gas will diffuse itself upwards into a light one, and a light one descend into a heavier one. In a closed apparatus this goes on till the two gases are equally mixed, when, as in the case of the oxygen and nitrogen of our atmosphere, they show no tendency to separate again. Light gases diffuse themselves more rapidly than heavy ones, where the conditions of the experiment admit of the difference being shown. Now, it has been already mentioned, that the atmospheric stream passing along the smaller bronchial tubes in the direction of the air-cells becomes progressively more and more gentle, and, as the air-cells themselves are really so many little culs-de-sac, having no thoroughfare, so to speak, it is certain that there can only exist a forward and backward or entering and retreating movement to and from the air-cells and the very finest air-tubes. Moreover, as the quantity of air which enters the lungs at each ordinary inspiration—20 cubic inches in the adult —is so small in proportion to that permanently retained in their tissue, namely, 170 cubic inches, it appears almost impossible that any of the entering stream should ever penetrate, by its own acquired impetus, into the air-cells themselves, and mix with that contained in their interior. But the diffusive property of gases would here undoubtedly come into play; for the air in the air-cells and finest tubes, being charged by the respiratory process with an excess of carbonic acid, in comparison with the newly-entering stream which approaches and is in continuity with it in the somewhat larger tubes, a diffusion of this carbonic acid would necessarily take place in the direction of these latter, whilst the oxygen from the air, or air itself, would diffuse in the opposite direction, towards, and into, the air-cells themselves. In this way the ultimate mixture of the gases, with all its important consequences, is effected, not by an intrusive agitation, but by a quiet physical process, beautifully adapted to the delicacy of the structures here brought into actual relation with the external atmosphere and subjected to alternate distension and contraction, as well as to the constant force of the heart's action.

In the next place, we may trace an analogy between the phenomena of the escape of carbonic acid from and the entrance of oxygen into the blood through the walls of the capillaries and the moist lining membrane of the air-cells, and those which take place on submitting gases to somewhat similar conditions, by placing them on each side of a moistened, but dead, animal membrane. If a dry porous substance, such as a thin layer of plaster of Paris set and thoroughly dried, be interposed between two dry gases, the phenomena of mutual diffusion take place all the same, though modified slightly by the relative facility with which certain gases pass through the porous substances employed. But if a moist membrane, such as a piece of wet bladder, be interposed instead, then the phenomena are altogether different, and the case is no longer one of simple diffusion; for the gases do not pass through the moist membrane in the gaseous form, but each is dissolved in the fluids of the wet membrane, and then evaporates as it were on the other side. This is exactly what must happen in the case of the respiratory interchange of carbonic acid and oxygen, between the blood and the air, within the lungs. Blood, as can be shown after its removal from the body, contains carbonic acid, oxygen, and nitrogen. The combined or dissolved carbonic acid passes, in a state of solution, through the moist membranous walls of the capillaries and air-cells, and then evaporates from the inner surface of the latter into their cavities; whilst at the same time, oxygen from the air, becoming dissolved in the fluid of the membranes, enters the blood also in a state of solution. Probably all three of the gases above mentioned take part in this process, but it is chiefly performed by the carbonic acid and the oxygen. In experiments on dead moist membranes, it is found, as might indeed be anticipated, that the rate of passing through and of course the general result of the interchange between any two gases, depend on the relative degree of solubility of the two gases employed; and carbonic acid being more soluble in water, passes through quicker than either air or oxygen itself. In respiration, however, it is believed that the quantity of oxygen which enters the blood is rather more than that of the carbonic acid which passes out, and therefore, although the physical conditions of the interchange here harmonize with those experimentally obtained out of the body, it must be that there is besides some collateral chemical or chemico-vital attraction between the pulmonary tissues or the venous blood and oxygen, tending to make them seize that gas, which, then, by displacing carbonic acid, converts the venous into arterial blood.

The average quantity of carbonic acid given off in 24 hours from the lungs of an adult is about 24,623 cubic inches, corresponding with 7¾ oz. avoirdupois of carbon. The quantity of oxygen absorbed would be 27,086 cubic inches, being on an average as 11 to 10 in comparison with the carbonic acid; and, as air once inhaled loses a fifth part of its oxygen, five times that amount, or 135,430 cubic inches, corresponding with 648,000 cubic inches, or 375 cubic feet of *unrespired* air, is necessary for each man's use daily,—calculating 18 respirations per minute, of 25 cubic inches each, to allow for occasional exertion.

It is from the capillaries of the air-cells also that the *halitus* or watery vapour of the breath is principally given off, though some of this doubtless proceeds from the moist surfaces of the bronchial tubes, trachea, and other passages through which the air has to pass out of the body. The quantity of watery vapour exhaled in twenty-four hours is usually from 14 to 20 ounces; this is not *pure*, but contains some organic matter which is very prone to putrefy, and must be highly injurious to breathe over again in any quantity.

The efficiency of the lungs in different animals is greatly influenced by the comparative fineness of the pulmonary capillaries, their number, the closeness of their meshes, and the extent to which they are exposed to the air. In all these respects there is a strict relation between them and the activity of the respiratory functions. Usually, the air reaches them only on one side; but in some animals, as explained in speaking of the thinning of the walls of the air-cells, both sides may be acted on. In birds, as an extremely perfected arrangement, the capillaries, besides forming close meshes on the air-cells, are said actually to project unsupported into their interior; so that the air passes through and through the little spaces between the vessels. It is doubtful, moreover, whether these vessels are covered by an extension of the lining membrane of the cells, and if, as stated by some, they are naked, there remains nothing between the blood and the air but their own thin walls.

4. Certain other *physical* and *physiological* conditions which influence the activity of the organs of respiration can only be briefly glanced at here.

The density, temperature, and purity of the air, and the constitution or quality of the blood, most materially affect the respiratory process. Thus, the amount of interchange between the oxygen and carbonic acid increases with the density of the atmosphere, and diminishes as this becomes more rarefied, as in great altitudes above the level of the sea. It is increased in low temperatures, and diminished by higher ones. It is in direct ratio with the quantity of oxygen in the air, being unnaturally exaggerated by an excess of that element, and enfeebled in air deprived more or less of it. Respiration is, therefore, more active in the country than in towns, in open than in confined spaces or close apartments, where the air, by being breathed over and over again, is charged with carbonic acid in place of so much oxygen, and with other impurities. Air containing more than six per cent. of carbonic acid is unable permanently to support respiration at all.

The blood being the matter to be acted on in respiration, and having, as it were, a sort of attraction for the oxygen, its richness in solid particles, which goes on increasing with the general activity of all the organic functions, from the lowest cold-blooded fish up to the hot-blooded birds, influences the respiratory function directly according to the quality and quantity of its constituents. Hence, also, in man as well as animals, respiration is increased during digestion, and diminished by fasting.

The direct relation between the activity of the respiratory function and the general functional activity of any given animal, has been frequently alluded to in the preceding pages. It is a great physiological law. It would be impossible for the frog and the mouse, each retaining respectively all its other functions, to exchange their respiratory organs; for just as the former would be destroyed by the respiratory activity of the latter, so would the latter die of inanition with the feeble respiration of the former. So, too, in ourselves, the quiet respiration of sleep would be inadequate to sustain great muscular efforts, whilst that required to support the body in violent exercise would be wholly incompatible with repose. Respiration is always more active during effort, and during the day, in comparison with its amount during rest, and in the night, even if we do not sleep. It is modified also by age, sex, and the condition as to health,—in these instances, and most of those above mentioned, its activity being indicated by a more frequent repetition of the respiratory act, and at the same time, of the pulsations of the heart. In regard to differences of age and sex, the relative capacity of the chest has also to be taken into account. The absolute amount of respiratory interchange becomes gradually greater up to the age of thirty, beyond which it diminishes somewhat; but in proportion to the bulk of the body, it is greater in children than in adults, corresponding with the superior frequency of the respiratory movements and the pulse. It is greater in males than in females, where the relative capacity of the chest may explain the difference. In cold-blooded animals, the pulse, and also the act of breathing, are slowly repeated; whereas, in hot-blooded creatures, they are both very rapid. In the human subject, and in animals generally, the relation between the respiration and the pulse is about 1 to 4; so that in man, with an average pulse of 72, the respiration is about 18 per minute. The respiration is increased in some diseases, and lessened in others.

The astonishing structural contrivances witnessed in the respiratory organs, and the admirable union of physical, chemical, and vital actions occurring in the performance of their important office, render these organs peculiarly fit objects for popular study, as examples of Divine design. In the next diagram, the mode in which the blood conveys the oxygen through the body will be described, whilst the action of the oxygen on the blood and tissues, and the connection of this with the evolution of animal heat, will be explained with diagram No. 9, in speaking of the waste and nutrition of the tissues.

Perfect respiration is necessary to insure vigour of body and mind; but the internal lung-surface, ever accessible to the air, is not only a chief inlet of life and health, but will rapidly absorb a deadly gas, or slowly inhale a fatal miasm. *Imperfect* respiration is a serious evil to the animal economy. The blood, no longer purified, is loaded with baneful materials, the tissues are not properly nourished and stimulated, the various organs are enfeebled, the vital powers lowered, and the body falls an easy prey to epidemic or contagious disease. There can be little doubt, too, that whatever the nature of consumptive disease may be, or whatever individual predisposition it may require, its actual development too frequently reckons amongst its exciting but *removable* causes a defective respiration; such as the repeated inhalation of bad air in over-crowded workrooms or unventilated sleeping-apartments. Complete *arrest* of respiration—whether from pressure on the chest, strangulation, impaction of a solid body in the air-passages, submersion in water, or deficiency of oxygen, as in the case of fire-damp and the stagnant gas of brewers' vats or wells—causes death by asphyxia, or suffocation. Instinct or prudence usually protects us against such sudden calamities; but it is a duty also to guard against the insidious evils attendant upon the protracted breathing of impure air, and to secure at all times, and under all conditions, that great necessity of our organization, a sufficiency of pure air not immediately respired before and free from all effluvia.

The natural source of this, the atmosphere, always contains a certain, but not injurious, trace of carbonic acid, amounting to $\frac{1}{20}$th of a cubic inch in 100 cubic inches. This is essential to the vegetable world; for plants absorb and decompose that gas, fix its carbon in their tissues, and give back the oxygen to the air again. Hence they reverse the action of animals on the air; and by these two simple but grand compensating organic processes, uniformity of composition of the atmosphere is secured, and the opposite necessities of the vegetable and animal kingdoms are mutually subserved. Diffusion and the action of currents in the air continuously dilute its incidental impurities, blend its interchanging constituents, and enable the oxygen to perform a very important function within the air itself; namely that of oxydating noxious substances which it may contain.

Supposing, as already mentioned, 375 cubic feet to be the quantity of air which an adult man requires to pass through his lungs daily, it does not follow that if he were to live entirely in an air-tight room, measuring 375 cubic feet (say 7 feet long, 5 wide, and 10½ high), and opened only once in the twenty-four hours, that his health could be long preserved, even though he might survive the experiment; for after each inspiration, the air confined in the room would become progressively tainted with exhalations, loaded with carbonic acid, and, in equal ratio, robbed of oxygen. It would therefore soon be utterly unfit for healthy respiration. Hence the necessity for *Ventilation*, which consists in providing for the gradual escape of the impure air, and the entrance of fresh air in its place. Even then it has been found desirable to allow at least 800 cubic feet of space for each occupant of a working or sleeping apartment.

No. 4.—The Organs of the Circulation.

THIS diagram is intended to exhibit the parts concerned in the distribution of the blood through the body, or *Organs of the Circulation*, that is to say, the *Heart* and *Blood-vessels*.

Fig. 1 shows the heart in its natural position, and, issuing from it, the principal blood-vessels proceeding to various parts. In front of the neck the muscles are removed, and, lower down, the thorax and the abdomen are laid open, much in the same manner as in the central figure of diagram No. 3; but the diaphragm is here cut across from side to side, so that the posterior part only of this musculo-tendinous partition between the chest and abdomen is left attached to the vertebral column and the ribs.

From the cavity of the thorax, the lungs, the bronchi at their roots, and also the pericardium, or sac which surrounds the heart, have been removed. From the abdomen all the viscera have been taken out, excepting the left kidney. In this way the heart itself, and the great blood-vessels in the chest and in the abdomen, are freely exposed to view. In the neck, and in the limbs of the right side, certain muscles have been partly or entirely removed, so that the main trunks of the blood-vessels, which are here deeply seated, may be more conveniently traced. It must also be understood that much loose cellular and fatty tissue, which surrounds and supports the vessels, both in the body and the limbs, has been cleared away. On the face, and on the limbs of the left side, the superficial muscles with their tendons are displayed. In front of the ear, and below the lower jaw, are shown two bodies called *Secreting Glands;* these produce saliva, and are named *Salivary Glands*. With the exception of the pulmonary artery, *e*, which is coloured blue, all vessels belonging to the kind called *arteries* are tinted red; whilst those coloured blue are named *veins*.

Fig. 2 is a plan showing the course of the blood to, from, and through the Heart.

Figs. 3 to 6 relate to the internal Valvular structures of the heart.

Figs. 7 and 8 show the great artery of the body, named the Aorta, the valves at its commencement, and the places of origin of its branches.

Figs. 9 and 10 are plans showing the Valves of the Veins.

Fig. 11 illustrates on a highly magnified scale, the arrangement of the network of minute vessels, called the Capillary Vessels, which connect the final branches of the arteries with the commencing branches of the veins.

Fig. 12 shows the microscopic elements, named the Corpuscles of human blood.

Fig. 13 displays the internal structure of the Kidney.

Muscles.

Before describing the proper subject of this diagram, viz., the organs of circulation, it will be convenient to enumerate the muscles which are depicted in its principal figure. Many of these having already been described in diagram No. 2, their names only are given in the annexed table of references. There are many points in the general position and arrangement of the bones and muscles, shown in this figure, which may be studied with advantage in connection with diagrams Nos. 1 and 2.

Muscles on the Face.

1 Frontal portion of left occipito-frontal muscle.

2 Auricular muscles, consisting of small scattered bundles of muscular fibres, which either raise the ear, or draw it backwards or forwards.

3 Orbicular muscle of the eyelids.

4 Compressor of the nose.

5 Levator of the nose and upper lip.

6 Zygomatic muscles.

7 Orbicular muscle of the mouth.

8 Square muscle of the chin.

9 Triangular or depressor muscle of the corner of the mouth.

10 Buccinator, or cheek-muscle.

11 Masseter muscle.

Muscles of the Upper Limb.

19 Deltoid.

22 Biceps of the arm.

23 23 Anterior brachial muscle.

26 Long supinator of the radius.

27 Long radial extensor of the wrist.

28 Tendons of the same, and of the short radial extensor of the wrist.

29 Tendons of the common extensor of the fingers.

30 Three extensors of the thumb.

36 Pronator of the radius.

37 Radial flexor of the wrist.

42 Abductor of the forefinger; draws the forefinger away from the middle finger.

Muscles of the Lower Limb.

45 Left psoas muscle, the right being partly cut away.

46 The iliac muscle.

50 Tensor muscle of the fascia of the thigh.

50′ Part of that fascia left to show its expansion over the knee-joint.

51 Rectus or straight muscle of the thigh.

52 External vastus muscle.

53 The external, and especially the internal, vastus is more completely exposed on the right thigh; the common tendon of the rectus and vasti muscles is plainly seen

lung, whilst others are given off in succession to the body generally. From the lungs, the renovated or oxygenated blood is brought back by *pulmonary veins* to the *left auricle*, and from the body, the deteriorated or deoxygenated blood is brought back by *systemic veins* to the *right auricle*. The two streams are then discharged by the two auricles into the single ventricle, whence the *mixed* blood, partly renovated and partly deteriorated, pursues the same divided course as before, partly to the lungs and partly to the body.

In the next higher forms of lunged animals, the reptiles, there are also *two auricles;* but the *ventricular part*, although externally single, becomes at first, in the lowest forms, as the serpents, turtles, and lizards, partially, and in the highest forms, as the crocodiles, almost completely separated by an internal septum, into *two compartments*. From one of these,—the *right* compartment, the pulmonary arteries proceed to the lungs, the blood from which returns by pulmonary veins to the left auricle; whilst the systemic or aortic arteries proceed from the *left* ventricular compartment to the body, from which the blood is returned by systemic veins to the right auricle. The two auricles, one filled with renovated, the other with deteriorated blood, discharge their contents into the single ventricle, within which the two streams are more and more thoroughly separated in proportion as the partitioning septum is larger, and are kept almost distinct when that partition becomes, as in crocodiles, nearly complete between the two compartments. The tendency of this separation of the two kinds of blood, when it takes place, is more and more perfectly to direct the deteriorated blood of the right auricle through the right ventricular compartment into the pulmonary circulation; and the renovated blood of the left auricle through the left ventricular compartment into the systemic circulation.

Moreover, the direction of the currents blending within the ventricle and the places of origin of the systemic arteries are such, that although, in all cases, the blood sent to the body is more or less mixed, still a larger portion of renovated blood is sent to the brain, head, and forepart of the body, and a larger portion of that not renovated to the hinder part of the animal.

In the final step, from the cold-blooded to the warm-blooded vertebrata,—namely, in birds and mammalia including man,—the separation of the ventricle into two cavities is complete. There are now *two auricles* and *two ventricles*, each auricle having its own ventricle, and each ventricle giving off its proper artery,—the *right* the *pulmonary artery*, and the *left*, the *systemic artery* or *aorta;* so that now no admixture of the renovated and deteriorated blood-streams takes place in the heart; but the two circulations, *pulmonary* and *systemic*, as we shall immediately trace more in detail in the human body, are perfectly separate, and the so-called double circulation is complete.

Course of the Blood in the Human Body.

Fig. 2. By the aid of this diagram or plan, and of the actual representation of the heart together with the main lines of blood-vessels, given in fig. 1, the course of the circulation through that organ, the lungs, and the body, may be distinctly followed. In this coloured plan the right auricle and ventricle, and the blood-vessels connected with them, are tinted blue, and the left auricle and ventricle, and their vessels, are pink, conventionally indicating the hue of the blood which they contain.

The blood returning dark and deteriorated from all parts of the body along the *systemic* *veins*, is poured into the *right auricle*, *c*, by the *superior vena cava*, *a*, and the *inferior vena cava*, *z*, and also by a small vein called the *coronary vein* (shown in fig. 3, diagram No. 3), which returns the blood from the walls of the heart itself. From the right auricle it is propelled into the *right ventricle*, *d*, and by it is driven on through the *pulmonary artery*, *e*, and its right and left branches, into the two lungs. In the capillaries of the lungs, as already explained in the account of those organs given with diagram No. 3, the effete blood exchanges carbonic acid for the oxygen of the air, becomes of a bright red colour, and regains its vivifying qualities. Then returning by the *pulmonary veins*, *f*, *f*, into the *left auricle*, *g*, it is propelled into the *left ventricle*, *h*, and is thence forced by that ventricle through the *aorta* or *systemic artery*, *i*, *i'*, and its various branches, into all parts of the body. In passing through the capillaries of the various organs and tissues, the blood parts with nutritive material, expends its vivifying properties, and, now containing more carbonic acid and less oxygen, and receiving into its current by absorption certain used up and waste materials from the tissues, becomes changed from a bright to a dark red colour, and, thus deteriorated or effete, returns along the *systemic veins*, *a* and *z*, to the right auricle, *c* again,—thence to pursue a similar course to that we have just traced.

The Heart.

The human heart, as shown in fig. 1, is a conical muscular organ, weighing from ten to twelve ounces in the male, and from eight to ten ounces in the female. It is about the size of the closed fist; its base reaches from the fourth to the eighth dorsal vertebra, and its apex beats, during life, on the left of the sternum, opposite the interspace between the fifth and sixth ribs. From what has already been stated, it can now be understood that it is a hollow organ, and is completely divided internally into a right and left half,—that each half consists of two parts or cavities, one called an auricle, the other a ventricle,—that the auricle and ventricle of the same half communicate freely with one another, but that those of opposite sides have no direct communication.

In figs. 2 to 6, these four cavities are thus indicated:—the right auricle is in all cases marked *c*, the right ventricle, *d*, the left auricle, *g*, and the left ventricle, *h*. As to the auricles, which receive the blood returning to the heart, and merely propel it into the ventricles, their muscular walls are thin, as seen in fig. 3; but the ventricles, which have to force the blood out from the heart through the lungs or the body, have, as shown in the same figure, muscular walls of considerable thickness. The capacity of each of the four cavities is about four ounces; and it has been calculated that the left ventricle exerts a force of about thirteen pounds at each contraction.

At every beat of the heart, first the two auricles contract, and then quickly afterwards the two ventricles, the two auricles acting together, and the two ventricles together,—the contraction of both kinds of cavities being called their *systole*, whilst their dilatation is called their *diastole*.

The number of times the heart beats in a minute may be counted by the pulse, which is, on an average, from 70 to 75 per minute in an adult; in the infant it is much quicker, varying from 100 to 120. In old age it is less, averaging from 56 to 65. The female pulse is quicker than the male by nearly ten beats in a minute. The pulse is increased by muscular effort, and during digestion; it is quicker in the morning than in the evening;

it is variously influenced by mental emotion. It has been noticed, that, doubtless owing to the muscular exertion needed, the pulse, in the standing posture, is about twelve beats more per minute, and in the sitting posture about four more, than it is in a recumbent and perfectly quiescent position.

At every beat, a certain portion of dark blood, four ounces in an adult, goes from the right side of the heart to the lungs, and having become red, returns to the left side, whilst, at the same same, a corresponding portion of bright-red blood goes from the left side through the body, and having become dark, returns to the right side. The blood which leaves one side of the heart returns, therefore, to the opposite side of that organ; or, in other words, the two circulations,—the pulmonary or lesser, and the systemic or greater circulation,—end, one in the other, at the heart; and thus all the blood of the body passes in continuous rotation through both circulations. The total quantity of blood present at any moment in the lesser circulation, or in the lungs, is, of course, less than that contained in the greater circulation, or in the rest of the body; but the quantities displaced and renewed in each, at every beat of the heart, must be practically equal. For unless the quantity of blood thrown at each beat of the one ventricle were either equal, or nicely adjusted to that thrown by the other, the one circulation would either overtake, or else fall short of the other, and congestion in the blood-vessels must at last ensue. The loss by evaporation from the lungs in the moisture of the breath or halitus, is so small, in reference to each pulsation of the heart,—at most not one eighth of a grain,—that it need not here be taken into account.

In the completely double heart of man and other warm-blooded creatures, the pulmonary artery is of equal area with, or it may be somewhat larger than the aorta; but in the cold-blooded air-breathing animals, where the two sides of the heart are less and less perfectly separated from each other as we descend in the scale of organization, the pulmonary trunk in the same ratio becomes smaller and smaller in proportion to the systemic trunk, and, accordingly, a less and less quantity of the mixed blood thrown by the single ventricle goes through the simply-constructed lungs of those animals, in proportion to that which is sent through their bodies. It is, however, sufficient for their feeble respiratory power and the lower wants of their economy.

Indeed, there are no more beautiful examples of mutual adaptation between the anatomical arrangement of different organs in the economy of animals, than those presented by the respiratory and circulating systems. In particular, it may be observed that the accomplishment of the problem of varying the proportions of blood thrown into the pulmonary and general circulations in the requisite degrees in the different air-breathing cold-blooded vertebrata, involves the necessity for a communication between the two sides of the heart; for, as already shown, when these are completely parted off, the quantities thrown into each circulation must be equal, or obstructions would somewhere or other arise.

Furthermore, one must not omit to notice, that in passing from the cold-blooded reptiles to the warm-blooded birds, we find, accompanying the complete separation of the two sides of the heart, an extraordinarily increased accommodation provided in the numerous and highly subdivided air-cells for a vast pulmonary capillary network, which shall safely allow an equal quantity of blood to be driven through the lungs from the right side of the heart, as is impelled from the left into the entire body.

Internal Structure of the Heart.

The contraction of the hollow muscle called the heart being, as already stated, the chief source of the force employed in the circulation of the blood, it is necessary to examine into the mode in which this force is applied, so as to insure the movements of the current taking place continuously in definite directions. For it may be asked, why, since both the arteries and the veins are connected with the heart, is the blood moved along the two sets of vessels in opposite but unvarying directions with unfailing order, regularity, and precision?

This is accomplished by means of internal membranous flaps or *Valves*, placed some in the ventricles of the heart, and others at the mouths or entrances of the pulmonary artery and the aorta. The action of these valves, like those of a force-pump, is mostly *passively* mechanical; but those situated within the ventricles are also under the *active* governance of certain parts of the muscular substance of the heart itself.

The position, form, attachments, and mode of action of these valves or flood-gates may be understood by studying carefully the illustrations given in figs. 3 to 8.

Figure 3.

In fig. 3, the cavities of the right side of the heart, *i.e.* the right auricle and ventricle, and also the commencement of the pulmonary artery arising from that ventricle, are laid open. At the mouth of the inferior vena cava, *z*, where that vessel enters the right auricle *c*, there is placed a large semilunar fold of membrane, called the *Eustachian valve*, which, during the contraction of the auricle, more or less completely prevents the blood passing down into the vein. At the mouth of the superior vena cava, *a*, there is no such valve, the weight of the column of blood descending from the parts above apparently offering sufficient resistance to the auricular contraction;—not, however, a complete resistance,—for each time that the auricle beats, a backward pulsation, called the *venous pulse*, takes place, and is even visible in the great veins of the neck.

The mouth of the coronary vein, already mentioned as returning blood from the substance of the heart itself to the right auricle, is provided with a very perfect and distinct valve, to prevent the regurgitation, which would otherwise inevitably take place, into the proper vessels of the heart. But no very perfect valvular, or other contrivance to prevent inconvenient reflux, is needed at the entrance or mouth of either vena cava; for during the contraction of the right auricle, *c*, the corresponding ventricle, *d*, is being relaxed or dilated; so that the blood, passing more readily in the direction of least resistance, is rather urged into the ventricle than back into the veins.

The ventricle, when fully distended, contracts powerfully upon its contents, and now a large and most perfectly contrived and accurately fitted valve comes into operation. This is the *tricuspid valve*, *t*, so called because it consists of three pointed parts or segments. Each segment is composed of a triangular fold of membrane, having one side attached, and the two others comparatively free. The attached edge or border, as seen in the figure, is closely connected with the rim or margin of the wide opening leading from the auricle into the ventricle, named the right auriculo-ventricular opening; the two other edges or borders are directed towards the cavity of the ventricle, within which, indeed, the segments of the tricuspid valve are entirely placed. These two last-named borders are not altogether free, but are fastened to the inside of the ventricle by little slender tendinous cords, which not only prevent the three segments of the valve from being ever thrown back into the auricle, but which, acted upon by certain short fleshy columns connecting them with the sides of the ventricle, assist, when the ventricle contracts, in spreading out the segments of the valve across the auriculo-ventricular opening. The pressure of the blood in the contracting ventricle completes the closure of their margins, and thus that fluid is effectually prevented from making its way back into the right auricle. Hence, taking the direction of least resistance, the stream of blood is driven into the pulmonary artery, *e*, and so along the right and left branches of that vessel into the lungs, distending and somewhat dilating the elastic arterial tubes through which it passes.

The right ventricle now ceases to contract, its walls become relaxed and its cavity enlarged, so that the column of blood just driven by it into the arteries leading to the lungs would be forced back again into the ventricular cavity by the resilient action of the elastic walls of those vessels, were it not for another valvular apparatus placed at the root or orifice of the pulmonary artery itself. Here three valves are found, called, from their shape, the *semilunar valves, s*. They consist of three semilunar membranous folds, having one border attached along the line of junction of the pulmonary artery with the ventricle, and the other border free or unattached, and turned in the direction of the interior of that vessel. When the artery is carefully cut open, these little folds appear like pockets or pouches fixed to its sides; they resemble in form and general character, the corresponding semilunar valves placed at the root of the aorta, as shown in fig. 8, *s;* but they are not quite so thick and strong, nor is the little nodule in the centre of the free border of each so distinct. Owing to the direction of their free edges, these valves permit the passage of blood from the ventricle into the artery, but are speedily tightened out across the aperture of that vessel by any returning movement of the current, and then, meeting closely together at their free margins, completely arrest the retrogade course of that fluid. It follows, therefore, that the propelling force originated in the ventricular contraction, and then modified by the resilience or recoil of the distended elastic walls of the pulmonary artery and its branches, must, of necessity, urge on the blood through the capillaries of the lungs,—whence it passes along the pulmonary veins, which conduct it to the left side, *i.e.* to the left auricle of the heart.

In the mean time, the ventricle, already described as having become relaxed and dilated, is refilled from the again contracting auricle, which, in its turn, has regained a supply, during its own dilatation, from the two venæ cavæ and the veins of the heart itself. The distended ventricle once more contracts, again the tricuspid valve closes, a fresh portion of blood, passing by the semilunar valves, is propelled into the pulmonary artery, and being prevented from returning by the sudden closure of those valves, is sent on its way through the blood-vessels of the lungs; and so the same phenomena are repeated at every beat of the heart.

Whilst the right side of the heart is thus receiving successive portions of dark blood from the body, and is transmitting them to the lungs, the left side of the heart is receiving similar successive portions of aërated blood from the lungs, and is transmitting them to the body. For, as already mentioned, the two auricles act simultaneously, and so do the two ventricles immediately after them.

Now, the valves on the left side of the heart correspond in arrangement and action, though not quite in form and structure, with those on the right side.

Thus there are no valves at the entrance of the pulmonary veins into the left auricle.

At the margin of the left auriculo-ventricular opening, there is found a very strong valve corresponding at the tricuspid valve, but consisting, however, of two segments instead of three, and therefore called *bicuspid.* Its two large segments or flaps project into the left ventricle, and its free edges are provided with little tendinous cords and muscular bundles to maintain them within the ventricle, and to assist in their perfect closure. Lastly, at the commencement of the aorta, as shown in fig. 8, there are three pocket-shaped or *semilunar valves*, *v*, corresponding with those at the commencement of the pulmonary artery.

The left cavities of the heart are not laid open in fig. 3, because, being turned from the spectator, the view would be confused. Nor need the action of the valves be described in detail, for it is identical with that of the valves upon the right side. It may be stated, however, that the valvular structures of the left side of the heart are very much thicker and stronger than those of the right side, corresponding, in this respect, with the greater thickness of the muscular walls of the left ventricle, which, having to force the blood through the whole body instead of through the lungs alone, contracts with greater force, and is provided with stronger valves to resist the comparatively greater strain upon them.

Figures 4 to 8.

These figures also relate to the valvular structures of the heart and great arteries.

Figs. 7 and 8 show the semilunar valves at the root of the aorta. In fig. 7 they are represented at *v*, connected with and closing up the opening of the enlarged part called the bulb of the aorta, *i*. In fig. 8 they are exposed by slitting up the commencement of the aorta, *i*, and the small connected piece of the left ventricle of the heart, *h*. The mode of attachment of the valves, *v*, their pocket-like shape, and the nodules in the centre of their free margins, which probably serve to resist the strain, and help more accurately to close the valves in the centre where they meet, are plainly seen. The two round openings in the aorta are the orifices of its two first branches, named the *coronary arteries*, which are the nutrient vessels of the heart itself, and are distributed to it, as shown in figs. 1 and 2, accompanied by the coronary veins, which return the blood from the walls of the heart into the right auricle.

Figs. 4, 5, and 6 are intended still further to illustrate the modes of action of the valves of the two sides of the heart, and of the two great arteries arising from it. In all three figures, the right and left auricles, *c*, *g*, are nearly entirely removed from the corresponding ventricles, *d*, *h*; and the pulmonary artery, *e*, and the systemic artery or aorta, *i*, are cut across, just beyond the semilunar valves, at their roots. The remaining part, or ventricular portion of the heart, *d*, *h*, is supposed to be turned with its base towards the eye, so as to show the auricular surface of the tricuspid valve, *t*, on the right side, and of the bicuspid valve *b*, on the left side; and also that surface of the pulmonary semilunar valves, *e*, and of the aortic semilunar valves, *i*, which is turned towards the interior of the blood-vessels to which they respectively belong.

In the three figures, the same parts are shown under different conditions of the heart's action.

Fig. 4 exhibits all the valves, loose, without action, and having their margins slightly apart, as they might be disposed by the anatomist after death.

Fig. 5 represents the state of the valves during the diastole or dilatation of the ventricles. The tricuspid and bicuspid valves are then opened to admit the passage of blood into the ventricles from the auricles, whilst both the pulmonary and aortic semilunar valves are closed, to prevent the reflux of blood from the great arterial trunks back into the ventricular cavities.

Fig. 6 shows the condition of the valves during the systole or contraction of the ventricles; at which time the tricuspid and bicuspid valves are closed, so as to prevent the blood being driven back into the auricles; whilst the pulmonary and aortic semilunar valves are thrown back against the sides of the great arterial trunks, to permit the contents of the ventricles to be projected into those vessels.

Some further remarks concerning the blood-vessels themselves, namely, the *Arteries*, *Capillaries*, and *Veins*, which, together, constitute the vascular system, will complete our view of the Organs of the Circulation.

The Arteries.

The arteries are the vessels through which the blood is driven by the heart into all parts of the body. They commence by two great trunks, one proceeding from each ventricle.

The trunk springing from the right ventricle is called the *Pulmonary arteries*, fig. 1, *e*. It soon divides into right and left pulmonary arteries, which enter the corresponding lungs, divide and subdivide within those organs, and, as already described and figured in diagram No. 3, are distributed exclusively to them.

The great arterial trunk arising from the left ventricle, *h*, gives off branches to the whole body, and is named the *Systemic artery* or *Aorta*. It is represented in fig. 1 of the present diagram in its natural position in the body,—being marked *i*.

By the additional aid of fig. 7, which represents the aorta detached from the body, the form, the course, and the several branches of this vessel may be better understood. It first passes towards the upper part of the thorax, and then bends down, in form of an arch, to gain the front of the vertebral column, by which it is supported and protected as it descends through the chest and abdomen to the point marked *i*, in fig. 1, where it ultimately divides into two great branches.

In passing from the thorax to the abdomen, the aorta perforates the diaphragm.

The first branches given off from the aorta, as already mentioned, are the two arteries which convey blood to the substance of the heart, named the *coronary arteries*. Their mouths or openings are seen just above the valves of the aorta in fig. 8, and their branches are represented in fig. 2, diagram No. 3, and in fig. 1 of the present diagram.

From the top of the arch of the aorta, three large branches are given off, the first of which subdivides quickly into two, so that four branches are found at the root of the neck. The two middle ones, *k k*, fig. 7, are the *right* and *left carotid arteries*, which supply branches to the head and face (see also diagram No. 3, fig. 1). The two lateral branches, *l l*, pass beneath the clavicle to reach the right and left upper limbs, and are called the *subclavian arteries*. In fig. 1, the vessel marked *l* is the right subclavian artery. The continuation of this vessel in the axilla or arm-pit is called the *axillary artery*, and in the arm, the *brachial artery*, *m*. In the forearm, the branches seen are the *radial artery*, *n*, and the *ulnar artery*, *o*; whilst in the hand, the branches are called *palmar arteries*, from which the *digital arteries*, proceeding to the fingers, are given off. By comparing the muscles exhibited on the right and left limbs, as well lower as upper, the amount of muscle removed and, therefore, the relative position and depth of the arteries, will be understood.

In the chest, the aorta gives off a branch to each of the spaces, right and left, between the ribs, except the upper one, which is supplied from the subclavian. These are called *intercostal arteries.* It also supplies little branches to the œsophagus, and nutrient arteries to the lungs.

Below the diaphragm, and, therefore, in the abdomen, the walls and viscera of that cavity receive many branches from the aorta. For the most part, only the commencements of these vessels are shown, the rest being removed with the viscera to which they are distributed. On the under surface of the diaphragm, in fig. 1, are seen its proper arteries, called *diaphragmatic* or *phrenic arteries.* The letter *g*, fig. 7, is placed on a short trunk called the *cœliac axis*, which divides into three branches for the stomach, spleen, and liver, and named accordingly, *gastric*, *splenic*, and *hepatic arteries.* Two large branches of the aorta for the right and left kidneys are called *renal arteries*, *r r*. In fig. 1, the left renal artery is seen entering the kidney. The arteries for the intestines, called *superior* and *inferior mesenteric*, are marked respectively, in fig. 7, *s* and *t*. Some small branches, similar to the intercostals, are called *lumbar*, and supply the loins.

Finally, the aorta divides, at its lower extremity, *i*, into two large arteries, *u*, *u*, called the *common iliac arteries*, each of which again subdivides into the *internal iliac*, which is distributed to the organs in the pelvis, and the *external iliac*, which descends into the thigh, where it becomes the *femoral artery*, fig. 1, *v*. After giving off a large deep branch called the *profunda artery*, the femoral passes down on the inner side of the thigh-bone to reach the space behind the knee-joint, called the ham or popliteal space, where it is named the *popliteal artery*.

In the leg, it again divides into branches, which, in fig. 1, are partly exposed by the removal of muscles,—*x* being the *anterior tibial artery*, which ends in *y*, the *dorsal artery of the foot*, and *w* being the *posterior tibial artery*, which runs down behind the inner ankle, and divides into the *plantar* arteries in the sole of the foot.

The arterial vessels thus rapidly enumerated are, after all, only the main trunks of the arterial system, from which, at various points of their course, very numerous branches of different sizes are continually given off, which again divide and subdivide many times in succession as they run through the various tissues and organs of the body,—some going to the brain, some to the organs of the senses, and some to the viscera of the thorax and abdomen,—some entering the bones, others supplying the ligaments and synovial membranes of the joints,—some ramifying in the muscles and their tendons, others supplying the sheaths of the muscles and the fasciæ,—some branching out in the subcutaneous cellular tissue and fat, and, lastly, others distributing themselves to the skin itself.

In every organ and in every tissue, the ultimate branches of these arteries become so small as not to be recognizable without the aid of a low magnifying-glass; and then, by still further subdivision, they pass gradually, as it were, into that fine microscopic network of transparent tubules called the *capillary vessels.*

The aorta and its branches, besides being surrounded by sheaths of cellular tissue and loose fat, are well protected not only within the body, but even in the limbs, where the main arteries are placed on the inner side of the corresponding bones, and always on the aspect of flexion of the several joints. Of course, the ultimate branches are to be found on all sides of a limb. The main vessels usually pursue a nearly direct course, whilst the finer branches are more or less tortuous. Most frequently a branch arises from its parent trunk at an acute angle, but occasionally the angle of origin is nearly a right angle, or even obtuse,—in this latter case, the course of the branch being retrograde.

The smaller branches of the arteries, and even rather large ones of arteries adjacent to each other in the body, join frequently together, so as to communicate freely with one another, or *anastomose*, as it is called. By this provision, the supply of blood is equalized, and insured againsts the effects of temporary pressure. In the limbs, these anastomoses are very free, usually about the joints, where they serve to maintain the circulation during flexion of a limb, or when its main artery is obstructed by disease or injury, or has been tied intentionally by the surgeon. In the last case they gradually enlarge, and establish what is commonly called a *collateral circulation*,—thus affording an admirable example of prospective care or providence in the constitution of the body against casualties inevitable in the present nature of things.

The structure of the arteries will be described in diagram No. 9. It is sufficient here to state that their walls are both elastic and contractile, and are so thick and resisting, that when cut across either in the living or dead body, their apertures remain open,—a circumstance which distinguishes them most markedly from the veins. Owing to the same conditions, too, they are usually found, on dissection, empty of blood, and filled only with air, which gains access to their interior when the body is opened. Hence, by the older anatomists, when the true course of the blood was not known, these vessels were erroneously supposed to convey "animal spirits," and were named arteries, from the Greek word *ἀηρ*, air or spirits.

With the exception of the valves at the commencement of the *pulmonary artery*, fig. 3, *s*, and those at the root of the *aorta*, fig. 7, *v*, the arterial system is destitute of valves,—in this respect also, as we shall see, differing from the veins. As a rule, the sectional areas of the branches of any artery added together, are larger than the sectional area of the artery itself,—an arrangement which tends, with the others just mentioned as to the mode of origin and tortuosity of the branches, and with the effects of friction, to diminish the force and retard the velocity of the current of blood moving from the heart onward through the arteries into the delicate capillary vessels. Nevertheless, along the course of the arteries, even of small ones, the force of the heart's action is still strongly exerted, so that on wounding one of these vessels, the blood escapes *by jets* corresponding in rhythm with the pulse. In the finest arteries, however, the stream is not only slower, but is at last converted by the resilience of the arterial coats into a continuous stream.

The Capillaries.

The possession of *capillary* vessels by any tissue, constitutes it a vascular tissue; and there are but few tissues in the living body which are non-vascular. These are the cartilages of the joints, certain transparent parts of the eye, including the clear coat in front called the cornea, certain parts of the teeth, the cuticle or outer skin, and its appendages the nails and hair.

Fig. 11 represents, in a plan magnified about 200 diameters, the capillary blood-vessels of one of the multitudes of little projections called villi, with which the internal surface of the small intestine is everywhere crowded. It is introduced to illustrate generally the manner in which the smallest arteries, such as that here marked *a*, terminate in the capillary vessels, *c*, and the way in which the minute veins, such as *v*, commence from the capillary network. It is copied from a representation of an intestinal villus of the hare.

The capillaries, therefore, as already mentioned, are intermediate between the terminations of the arteries and the commencements of the veins, although, it must be understood, there is no abrupt line of demarcation between them and those two kinds of vessels.

The structure of the capillaries, the mode in which they are arranged in the different tissues, and their varieties of size, are fully illustrated in diagram No. 9, figs. 58 to 64.

For the present, it is necessary clearly to comprehend that, as represented in fig. 11, just described, the capillary vessels have distinct walls, so that the blood passing through them runs in definite tubes, and is not merely strained through interstices or intervals between the component elements of the tissues and organs of the body. The stream of blood which moves through them is no longer pulsatile as in the arteries generally, but continuous as in the finest arterial ramifications, from which the capillaries arise. The current is, however, slower, owing to the great increase in the number and area of the capillaries as compared with the last arteries. The force of the heart is still the active agent in producing the movement of the blood, but, according to some authorities, it is exhausted in the general capillary network; whence it is supposed that a certain repulsive force, connected with the nutritive changes in the tissues, urges the stream onward into the veins. Experiments, however, justify the conclusion that the force of the heart is still felt beyond the capillaries, *i. e.* in the veins themselves.

Be this as it may, it is only as it passes through the capillaries that the stimulating and nutritive properties of the blood begin to exercise their influence on the living tissues. Through their thin walls a nutritive fluid exudes, to supply materials for the waste that is constantly going on in the tissues during life; through them also some of the oxygen of the arterial blood probably escapes, to act upon those tissues; and through them, in the form of a returning current, carbonic acid and the other products of the wasting and oxidizing tissues come back or re-enter the circulating current, to go on into the veins. The capillaries are the proper seat of this exudation, but the process of absorption may also be participated in by the finest veins. The number of the capillaries in any tissue is just in proportion to the activity of the vital changes in it; and, in non-vascular tissues, all such changes, being carried on at a greater distance from the capillary streams, are therefore more feebly and slowly performed.

The Veins.

The *Veins*, commencing by little twigs from the capillary network, in the absorbing functions of which they probably participate, join together to form larger and larger branches, which, combining at last into a few principal veins, terminate in certain large venous trunks, which empty themselves into the auricles of the heart.

The *Pulmonary Veins*, coming from the lungs, end by four trunks, two on each side, in the left auricle.

The veins from the body generally, or *Systemic veins*, combine to form three trunks, one small and two large, which end in the right auricle.

Of these, the small one, aided by a few still smaller, returns the blood from the substance of the heart only, and is called the *coronary vein.*

One of the large veins, marked *a* in fig. 1, receives the great veins from the head, upper limbs, and thorax, and is called the *superior vena cava.* The other, still larger, named the *inferior vena cava,* returns the blood from the lower limbs, and the viscera and walls of the abdomen and pelvis.

The blood returned from the stomach and from nearly the whole of the intestinal canal, as well as that from the pancreas and spleen, is not poured *directly* into the inferior vena cava, but first performs another circulation through the substance of the liver. For this purpose, the veins from those parts are gathered into one large vein, called the *portal vein,* which enters the liver, and divides therein, like an artery, into smaller and smaller branches, which end in a capillary network.

From this a new set of veins arise, which, uniting into larger and larger branches, combine to form a few trunks called the *hepatic veins,* which pass from the back of the liver into the vena cava inferior, immediately below the diaphragm, as seen at *b.*

This supplementary circulation is called the *Portal circulation.* It will be again alluded to in diagram No. 6.

The veins which return the blood from the kidneys, named the *renal veins,* enter directly into the inferior cava. In cold-blooded animals there is a sort of portal circulation through the kidneys; for, like the liver, they receive blood from venous sources.

In the limbs, there are two sets of veins, one superficial and the other deep; so that, as regards their distribution, they differ from the arteries. The *deep veins* of the limbs accompany the arterial trunks, and excepting the larger vessels, which ultimately enter the pelvis or the neck, they are usually double, as shown in fig. 1. They are called *venæ comites,* or companion veins, and bear the same names as the arteries with which they run.

The *superficial veins,* unaccompanied by arteries, are placed beneath the skin, between it and the fascia or general investment of the muscles, which serves, indeed, to support these veins as well as the superficial absorbent vessels, and the cutaneous arteries and nerves.

In the principal figure of diagram No. 3, the veins only are represented on the limbs of one side; in diagram No. 5, the veins and the absorbents; and in No. 7, the veins and the nerves.

The cutaneous arteries are small and tortuous; but the superficial veins are large, pursue a straighter course, and, perforating the fascia at certain definite points, end in the deep veins which accompany the arterial trunks.

The principal veins anastomose or join together in their course much more frequently and freely than the larger arteries. The superficial veins not only terminate in the deep veins, but are joined to them at frequent intervals by short communicating branches, which perforate the fascia. So also the two companion veins, which follow the arterial trunks, are joined together at intervals by short cross branches. These frequent and free communications between the venous channels are characteristic of the venous system, and are evidently intended to insure, under circumstances of temporary pressure or interruption in one set of vessels, the return of blood to the heart through others.

The structure of the veins is described with diagram No. 9. It may here be stated that their coats are much thinner than those of the arteries and not so elastic and contractile, but, on the contrary, are so thin and weak that they collapse when divided, both during life and after death. As will presently be described, they still further differ from the arteries in containing valves in their interior.

The venous current, like that of the capillaries, is continuous; so that a wounded vein bleeds not in jets like an artery, but in an uninterrupted stream. This is a point of some practical importance, for, coupled with the peculiar colour of the blood escaping from a wound, it serves to distinguish whether any accidental bleeding from the living body is venous or arterial. If it be venous, that is dark and continuous, it should be arrested by pressure on the wound and on the side of the wound away from the heart; if arterial, that is bright and jetting, by pressure upon the wound and between it and the heart; for, in the former case, the stream which supplies the escaping blood is returning to, and in the latter is coming from, that organ. In the exceptional cases of arterial *arches*, as in the *palm* (see fig. 1, in the right limb), pressure must be applied mainly over the bleeding point. A small pad of linen, held down by the thumb, is as useful and certain a method as any for an unskilled person to employ until assistance can be had.

Taken as a whole, the venous system is nearly three times as capacious as the arterial, though it is less so than the capillary system. Hence the rate of movement of the blood in the veins, though quicker than it is in the capillaries, is proportionately more sluggish than it is in the arteries.

In the veins the force of the heart, though reduced to its minimum, is by no means exhausted, and still constitutes, whether with or without the assistance of any force resulting from nutrient changes in the neighbourhood of the capillary network, an important, and indeed the chief, cause of the movement of the blood.

From the head and neck, the return of the venous blood to the heart, in the upright posture, is clearly favoured by the force of gravity, but in regard to the greater portion of the body, that is in every part lower than the right auricle, the blood returns to the heart in opposition to gravity. Furthermore, the deep veins of the limbs, subjected to the pressure of the adjacent muscles in action are too thin and weak to resist the effects of compression, which must continually tend to interfere with the perviousness of their canals.

Owing to these circumstances, the circulation of the blood through the veins back to the heart would be but inadequately performed, were it not for that admirable and wonderful contrivance of floodgates or valves in their interior, the position and arrangement of which, in fact, furnished the most important hint towards the demonstration of the true course of the blood by our illustrious countryman Harvey.

Figures 9 and 10.

The form, arrangement, and mode of action of these valves, are illustrated in the plans marked fig. 9 and fig. 10. They are further represented in diagram No. 9, fig. 50.

Fig. 9 is a vein laid open to show the valves *v v*. These are little delicate transparent semilunar or pocket-shaped folds of membrane, attached by their convex borders to the inside of the vein, but having their concave borders free, and turned invariably in the direction of the heart. Two, and sometimes, though rarely, three of these valves are placed opposite each other, at certain intervals, along a vein. When, therefore, the blood is passing onwards through such a vessel, as shown in the plan fig. 10, *a*, the valves are separated from one another, thrown back against the inside of the vessel, and offer no hindrance to the moving current. But when any obstacle, such as gravity, external pressure, or other resistance, prevents the onward movement of the blood, or tends to force it back upon the capillaries, the opposing valves quickly meet each other across the middle of the vein, as represented in fig. 10, *b*, and so effectually arrest any retrogade movement of the circulating fluid. The instant that the supposed obstruction is removed, however, the arrested blood moves on, and a fresh portion is transmitted between and beyond the valves, which at once open to allow it to pass. Moreover, owing to the existence of these valves, and to the frequent lateral communications between neighbouring veins, pressure, in almost any situation and direction, however apparently adverse, so far as regards its *local* effect upon any particular vein, to the onward flow of blood to the heart, is rendered available for the *general* progress of the circulation, through other branches, because, as must be obvious, the portions of blood held up by any set of valves can only be ultimately moved by that pressure in a direction towards the heart.

Valves are not found in the very finest veins; nor yet in the large venous trunks near the heart; nor in some veins of the abdomen, as those of the digestive organs and the kidneys; nor in those of the head, face, and upper part of the neck. They exist in all the veins of the limbs, and are strongest and most numerous in the lower limbs, where the force of gravity acts the most against the return of the blood. In the superficial veins of the lower limb, they serve to take off a certain amount of the weight of the long column of blood which the coats of those vessels would otherwise have to bear; and when, from long standing, the veins are dilated and become knotted or *varicose* as it is called, those valves are many of them destroyed, or so stretched or altered as to be quite inoperative.

There are no valves in the pulmonary veins, as though none were needed in so short a circulation as that through the lungs. The pulmonary veins also are not of greater capacity that the arteries, as is the case in systemic circulation.

This is a convenient opportunity for remarking that the return of the venous blood from the body to the right side of the heart, though largely and mainly due to the force exerted by the left ventricle through the arteries and capillaries, aided perhaps by a force originating in the capillaries themselves, is also influenced by the respiratory movements acting on the contents of the great veins as they are about to enter the chest. The expansion of the thorax removes atmospheric pressure from the heart and great blood-vessels within the chest as well as from the lungs, and so the returning blood enters the great systemic veins and the right auricle more freely during inspiration than during expiration, when its passage into the chest is, from an opposite cause, retarded. In proof of this, a certain fulness of the veins of the neck may be observed during expiration, and a subsidence of those vessels during inspiration; a phenomenon which is named the *respiratory venous pulse*, and which is quite different from the venous pulse due to the back action of the right side of the heart already described (p. 57). The inspiratory effort must, to a certain degree, retard the flow of blood out of the chest through the systemic arteries, whilst expiration would favour it, the effect being opposite to, but not so striking as, that observed in the case of the veins.

The pulmonary circulation is entirely performed within the chest, and in every part of it is subject, at any given moment of the respiratory act, to the same amount of pressure throughout; for there is no removal of pressure from the lungs which does not equally affect the heart and the pulmonary vessels; and *vice versâ*. The influence of the respiratory movements upon the circulation through the lungs is therefore different from that on the systemic circulation; but the one is nevertheless in direct harmony with the other. During inspiration, when the flow of blood to the right side of the heart is accelerated, the lung is expanded, the area of the pulmonary surface is increased, and the capacity of its capillary network for receiving blood is rendered greater; whilst, in expiration, comparatively speaking, the compressed lung is capable of receiving less blood, at the very same time that the flow of that fluid into the right side of the heart is being retarded;—thus harmoniously adjusted are even the subsidiary relations of the two different but mutually associated functions of circulation and respiration. In further proof of this harmony, it may also be observed, that there must exist a vital relation between the character of the blood received into either side of the heart and the peculiar excitability of the parts into which it is received; for the dark blood which acts as the proper stimulus to cause the right side to contract, will not adequately excite the left side, which is organized so as to require the bright-red blood as the proper excitant of its contractions. Hence, if the blood is not properly aërated in the lungs, it will not keep the left side of the heart alive. Again, it is obvious, that complete stagnation of the blood in the pulmonary capillaries, such as occurs in asphyxia or suffocation, must be followed soon by total arrest of the heart's action, the right side of which becomes overgorged with dark blood, while the left is nearly empty; and in that state these two cavities are found after death.

The heart is composed of involuntary muscle, but its fibres, forming an exception to the general rule belong to the *striped* variety. (See diagram No. 9, figs. 29 to 37.) Its movements, as already mentioned in regard to the pulse, are influenced by various conditions of mind and body, and though doubtless regulated by some part of the nervous system, the cause of the rhythmical character of its lifelong beats is still a mystery.

In connection with the remarks just now made on the peculiar adaptation of the right side of the heart to be stimulated by dark blood, it may be added that the right auricle is the last of all the striped muscular parts of the organism to lose its contractility as life becomes extinguished, constituting what the older physiologists have entitled the "ultimum moriens," or last part to die.

The Blood, and its Corpuscles.

Figure 12.

The blood forms about $\frac{1}{12}$th part by weight of the entire body, and it is calculated that it may circulate completely in about 1½ minutes. It is not a mere coloured solution of certain animal substances, but possesses a peculiar organization and special vital properties. In a word, it is itself *alive*, and may without any license of expression be termed a liquid tissue. Even in invertebrate animals, the circulating fluid contains little floating particles having definite colour, character, and form; but it is in the vertebrata that it attains its highest organization. In them, as may be seen under the microscope, on extracting and spreading out a drop between two thin pieces of glass, or as it is yet flowing through the capillaries or small vessels of the transparent parts of living animals, such as the web of the frog's foot or the wing of the bat, the blood is found to consist of a diffluent and apparently colourless fluid called the *liquor sanguinis,* or liquor of the blood, and of two kinds of corpuscles floating in it, named, according to their possession or want of colour, the *red*, and the *white* or *colourless corpuscles of the blood*, or *blood-corpuscles.*

The *liquor sanguinis*, or *plasma* of the blood, so called because it contains the plastic materials out of which all the tissues are built up or supported, is a strong solution of animal organic substances, such as albumen and fibrin, with much oily or fatty matter, and certain alkaline and earthy salts.

The red blood corpuscles, by far the more numerous, are the characteristic organized elements of this fluid. In man they are little circular disc-like bodies, having two opposite and slightly concave surfaces, and therefore somewhat thickened rounded borders. In fig. 12, *a* shows a red corpuscle lying on one side; *b* is one seen edgeways. Two others are shown, one overlapping the other, and three more adhering together by their surfaces and also seen edgeways. In blood, after it has been drawn from the body a little while, the red corpuscles frequently run and cling together in this way, forming long rolls like rolls of coins. These corpuscles are about $\frac{1}{3300}$th of an inch in diameter, and $\frac{1}{12000}$th inch thick, so that a pile of them one inch high would require 12,000 corpuscles. Their number in the blood is prodigious, nay, incalculable. It is to them that the blood owes its red colour; so that they are named red corpuscles, and are coloured red in this and also in No. 9 diagram; but the actual colour of the corpuscles seen individually under the microscope is a pale pinkish amber, the overlapping of a very few however giving a distinctly reddish hue, and the aggregation of many the characteristic blood-red tint. On the same principle the brilliant colours of the fluids contained in the large show-bottles in chemists' shops, are due to the great bulk of the solution, a small quantity of which poured out into a wine-glass appears almost colourless.

The white corpuscles of the blood are actually colourless, transparent, spherical or globular bodies, having an indistinct granular nucleus in their centre. One is shown at *c*, in the present figure, in which all the corpuscles are magnified about 3,500 times. These white corpuscles are rather larger than the red ones, but they are much fewer in number, ranging in a varying proportion of from 1 in 50 to 1 in 300. They closely resemble the corpuscles of the lymph which are figured and described in the next diagram.

Further information on the nature and uses of the red and white blood corpuscles and their relation to each other, on the chemical constituents of the entire blood, and the uses of its several parts in the animal economy, will be given with diagram No. 9, under the heads of Nutrition of the Textures, and Secretion.

Here the following general facts may be mentioned. The blood, the great circulating medium of the body, conveys oxygen to all the tissues, and takes the carbonic acid from them, as explained in the description of the respiratory organs. It is the source of all the nutrient material for the renewal of those tissues, which makes its way to them by the exudation of the liquor sanguinis through the capillary walls. It receives back again in part, perhaps, the unemployed exuded fluid, besides the products of the waste of the tissues, which are taken up or absorbed by the returning portion of the capillary vessels and the adjoining minutest veins, as explained already in the present diagram. It is the source from which the numerous bodies called secreting glands, such as the mucous glands, the salivary glands, the liver, and so forth, separate their variously constituted products,—such as mucus, saliva, and bile. In respiration, nutrition, secretion, and absorption, therefore, the blood is constantly parting with some materials and receiving others. The absolute loss is regularly supplied by the digestive process, through the agency of the Absorbent System, as will be described in the two succeeding diagrams. Lastly, the waste substances poured into it are being constantly expelled by a purifying process carried on in certain other glands called excreting glands,—such as the kidneys and the sweat-glands of the skin, which will be described in their proper places.

The blood, therefore, is continually subject to decomposition and recomposition, to loss and supply, to contamination and purification; and yet its quantity and quality must and do remain somewhere within certain limits the same, or else the health declines or life wears out, or, it may be, is quickly extinguished. Not only then pure air, but pure food, and the *due* exercise of all the organs in their proper proportions and relations of functions, whether muscular or nervous, digestive, absorbent, secreting, excreting, or respiratory, are necessary for the production and maintenance of perfectly healthy blood, whilst this again is equally necessary for the healthy performance of all those functions themselves. The benefits of a sound condition, and, be it remembered, the evils of unsound conditions, are therefore quickly reciprocated on the part of the various organs and the blood; and, as the nervous system, which will be explained with diagram No. 7, is that *bond* of *animal* and *organic* life, by which all parts of the body are mutually tied together and made sympathetic with each other, so is the blood the *chemico-vital bond* of the life of the entire system; it is the indispensable stimulating and life-giving current, ever flowing between part and part, ever acting and being reacted on, and incessantly fulfilling so many purposes and supporting so many processes absolutely necessary to existence, that the truth concerning it is most happily summed up in the scriptural phrase, "the life of all flesh is the blood thereof."

The Kidneys and the Supra-renal Capsules.

Figure 13.

One of the large glands, called the *kidneys*, being shown in this diagram in its natural position at the back of the abdomen, fig. 1, *q*, a section of that organ to exhibit its internal structure is added in fig. 13.

As just now alluded to in speaking of the uses of the blood, the animal economy is provided with many bodies of complex structure, called *Glands*, the purpose of which is to separate from that fluid certain products, which either are to be used up again in some process necessary to the maintenance of life, or else are cast out of the body as no longer useful, or even injurious or poisonous to it. The salivary glands, of which two are seen in fig. 1, one, *s*, in front of the ear and another beneath the lower jaw, separate saliva from the blood, or, as it is termed, *secrete* the saliva, a fluid which, as is well known, is used in the digestive process; the saliva accordingly is termed a *Secretion*. But such glands as those of the skin, and the two kidneys, which separate substances that are to be thrown off as no longer useful or positively injurious, are said to *excrete* their particular products, which are therefore called *Excretions*. The general structure and mode of action of the different glands in the body will be discussed in diagram No. 9, under the description of figs. 65 to 70.

The kidneys are two firm dark-red bodies, which are supported against the back of the abdominal cavity, in the region of the loins, one at each side of the vertebral column, on a level with the last dorsal and two or three upper lumbar vertebræ,—each being held there by blood-vessels, nerves, and the great excretory canal or duct, fig. 1, *f*, called the *Ureter*, which conveys the excretion of the corresponding gland down into its temporary receptacle, lodged deeply in the pelvis and named the bladder, *t*. The kidneys are also surrounded by much cellular tissue, which is loaded more or less with fat, and which further contributes to support and protect them in their position. They are placed altogether behind the lining membrane of the abdomen or peritonæum. They are about 4 inches long, 2 wide, and 1 thick, and weigh about 5 oz. each. The shape of the kidney is peculiar and well known, having given the name to the bean called the kidney-bean. On its concave border is a deep longitudinal fissure, called the *hilus*, which passes into the interior of the gland, and gives exit and entrance to the blood-vessels (see fig. 1), absorbents, ducts, and nerves.

The kidney is enclosed in a proper smooth fibrous coat, which closely invests every part of it, penetrating into the hilus also.

In a longitudinal section of the kidney and ureter, made through the hilus, as shown in fig. 13, in which the blood-vessels and nerves are supposed to be removed, the internal arrangement of the substance of the gland and of the excretory ducts can be easily understood. The solid gland substance consists of an outer *cortical* layer, and of a deep-seated embedded part called the *medullary substance.* The cortical substance, *c*, is continuous over the whole organ, measuring about two lines in thickness; but it dips also between the different portions of the medullary substance, which is arranged in a series of conical masses, called (after a celebrated Italian anatomist of the seventeenth century) the *pyramids of Malpighi.* The bases of these pyramids, of which there may be as many as 18, are turned in various directions towards the surface of the kidney, and, as well as their sides, are encompassed with the cortical substance. The summits of the pyramids, on the other hand, are turned towards the bottom and sides of the longitudinal fissure or hilus, where they project in the form of little eminences, called the *papillæ of the kidney*, *p p*. These papillæ, as well seen in the figure, are received into and are accurately embraced by certain short membranous funnel-shaped tubes or ducts called *calyces* or *infundibula*, which join together into other tubes, of course rather fewer in number, and these into two or three others, by the ultimate junction of which, the single large excretory duct called the *ureter*, *u*, is formed. The upper dilated part, *i*, of the ureter, as it emerges from the hilus, is named the *pelvis of the kidney;* its lower end penetrates obliquely the tissues of the bladder, into which it opens; its walls, and those of the divisions as high as the calyces, consist of a strong fibrous coat, of an imperfect muscular layer composed of involuntary muscular fibres, and of an internal lining mucous membrane, which is continuous with that covering the papillæ of the pyramids above, and with that of the bladder below.

The cortical substance of the kidney is reddish-coloured, soft and friable, and contains many little dark-red spots, called the *Malpighian corpuscles of the kidney*, which will again be noticed. The substance of the pyramids is firmer, deeper in colour, and striated from apex to base. Both substances are chiefly composed of minute closely-packed *tubules*, held together by a scarcely recognizable amount of an intermediate delicate areolar tissue and proper renal substance, and having the arteries, veins, and capillaries lying between and upon them, besides absorbents and nerves. In the cortical substance, the tubuli, measuring about $\frac{1}{600}$th of an inch in diameter, are remarkably *convoluted*, generally beginning by free closed commencements, but sometimes anastomosing together, so as to form loops, as shown in the plan in diagram No. 9, fig. 69. Entering the pyramidal medullary masses at all points of the bases and sides, these convoluted tubules become *straight*, and run in a direction towards the apices or papillæ. In this course, as also seen in the last-named figure, they unite together over and over again by twos, until they ultimately form about 400 or 500 larger straight tubuli, about $\frac{1}{400}$th to $\frac{1}{250}$th of an inch in diameter, which open by as many little orifices on the surface of the corresponding papillæ within the cavity of their *funnel-shaped* ducts or calyces. The straightness of the tubuli within the pyramids gives the striated appearance to those parts, in comparison with the granular aspect of the cortical part where the convoluted tubuli exist.

The tubuli themselves, which are the secreting tubes of the kidney, are composed of a transparent tubular basement membrane, lined with a thick glandular epithelium, consisting of polyhedral nucleated cells. At the mouths of the tubuli upon the papillæ, this epithelium passes into that which lines the mucous coat of the ureter and its divisions (see diagram No. 9, on the epithelium generally). At various points of the *convoluted* tubuli of the cortical substance of the kidney, either at their free closed commencements, or in the course of the loops which they sometimes form, are found little rounded sacs or pouches, communicating with the tubes, and each containing one of the little dark-red bodies called a Malpighian corpuscle, which projects into it, as shown in diagram No. 9, fig. 69. The epithelium lining these saccular dilatations is remarkably thin; it is probably also prolonged over the projecting part of the Malpighian corpuscles. These corpuscles, usually about $\frac{1}{120}$th inch in diameter, are, in reality, formed by the splitting up of a small artery into a *tuft* of smaller vessels; whence they have been also named *glomeruli*, which signifies little tufts.

The arteries of the kidneys, named the *renal* arteries, fig. 7, *r r*, of the present diagram, and seen also in fig. 1, are very large for the size of the organs they supply. After branching and anastomosing very frequently in the substance of the kidney, they end in a fine capillary network, which surrounds the secreting tubuli; many of them, however, in the cortical substance first enter the little glomeruli, and divide into a tuft of vessels in its interior, from which another vessel, by some considered to be a vein, and by others still an artery, arises, and passing out again divides and loses itself in the capillary network around the tubes. It is supposed that the thick epithelial cells of the tubuli effect the separation of the solid constituents of the renal excretion from the blood going through the capillary network, whilst the aqueous portion is merely exuded through the little vascular tufts of the Malpighian corpuscles, which, therefore, *if* this be true, act as flushing apparatuses to clear the fine tubuli of their more solid contents. The united products are discharged into the calyces by the minute openings of the tubuli upon the papillæ, and from the calyces they reach and descend along the common duct or ureter.

The veins everywhere commencing in the capillary network, end also, after many junctions and anastomoses, in a single large trunk for each kidney, called respectively the *right* and the *left renal vein* (see fig. 1, *r*), both of which join the ascending vena cava, *z*.

The blood passes through the kidney in enormous quantities. Comparing the transverse sectional areas of the aorta and of the two renal arteries, and contrasting these with the weight of the entire body and of the two kidneys, it may be computed that, in proportion to their weight and in a given time, 200 times as much blood passes through the kidneys as circulates through the body, taken generally. In its passage through these organs, it is being continually deprived of a certain quantity of the products of decomposition or waste in the tissues, especially it would seem of those of the muscular and nervous systems. Some of these products are so poisonous that if retained in the blood they produce disease and even death; and complete arrest of the function of the kidney is speedily fatal. Urea, uric acid, ammoniacal salts, and other less decompounded substances, contain carbon and hydrogen combined with nitrogen, whilst the alkaline and earthy sulphates and phosphates represent the sulphur and phosphorous of the tissues, together with soda, potash, magnesia, and lime. The other great depurating organs of the blood, besides the kidneys, are the lungs, as already explained, the skin, probably also some of the glands of the intestinal canal, and to a certain extent the liver. The renal and cutaneous or skin secretions, in quantity and in some other respects, counterbalance one the other.

In the higher classes of the invertebrate division of animals, certain excreting tubes, which seem to serve the purpose of kidneys, are usually found; and in the vertebrata they universally exist from fishes up to mammalia and man. The shape and structure of these organs vary much in each class, and in different genera of the same class. In all, however, straight and convoluted tubuli, with saccular dilatations containing Malpighian corpuscles with their vascular tufts, are found. In all cases too the products of the excretion are of the same kind; but in certain cases, as in birds, they are semi-solid, and in others, as in serpents, they are quite firm and even stony. Guano, that priceless discovery for the modern agriculturist, is chiefly the pasty renal excretion of sea-birds, spontaneously fermented and dried in great masses under a tropical sun.

The Supra-renal Capsules.

On the upper end of each kidney, as shown in fig. 1, on the left side, is a yellowish flattened triangular or cocked-hat-shaped body named the *Supra-renal Capsule.*

These bodies, which have a very peculiar structure, and contain in their tissue dark yellow, brown, and almost black colouring matters, belong to the class of ductless glands, *i. e.* of glands having no ducts leading from them. They are also called *blood-glands*, because any peculiar influence which they exercise on the blood passing through their tissues must produce an altered condition of that fluid as returned from them towards the heart. The Thyroid body, shown in front of the windpipe in diagrams Nos. 3 and 7, and the Spleen, an organ situated in the abdomen, and seen marked *m*, in diagram No. 3, fig. 1, and diagram No. 6, figs. 13 and 14, likewise belong to the class of blood-glands. The functions of the thyroid body and supra-renal capsules are quite unknown: those attributed to the spleen will be mentioned under diagram No. 6. A curious relation of co-existence, though not without some seemingly exceptional facts, has been quite recently shown to obtain between a certain bronze-coloured affection of the skin, accompanied by a gradual decline of the health, and a diseased state of the supra-renal capsules. That is at present the most interesting circumstance known concerning them.

No. 5.—The Lymphatics or Absorbents.

THIS diagram is intended to illustrate the structure, distribution, and office of a peculiar class of vessels called *Lymphatic or Absorbent vessels*, which, together with certain rather firm roundish or oval bodies connected with them, named *Lymphatic glands*, and a main trunk ending in the venous system, called the *Thoracic Duct*, constitute the Lymphatic or Absorbent system.

The central figure, 1, shows the general character and arrangement of the principal lymphatic vessels and lymphatic glands throughout the body,—the vessels being shown as white jointed cords, and the glands as little white bodies connected with them.

It may here be mentioned that the coats of the lymphatics are so thin, and the fluid which they convey is so transparent and colourless, that they are invisible in ordinary dissections, and can only be detected by special research.

They are usually displayed, or, as it is called, *demonstrated*, by being injected with quicksilver, which fills them out into jointed tubes, having a silvery appearance. Hence it is customary in anatomical drawings and diagrams to represent them as white upon a darker ground. But it must be distinctly understood that in the body, even when filled with their proper fluid, called *Lymph*, they are perfectly transparent, and escape all but the closest observation.

As will be hereafter mentioned, in one position and under certain conditions, these vessels become visible, owing to their conveying for a time a milk-white opaque fluid, which is called *Chyle*.

In this figure, such arteries and veins as are seen are coloured, as usual, red and blue; while the fascia, muscles, and tendons are tinted as in the other diagrams.

The lymphatics are so arranged as to form two sets, one *superficial* and the other *deep*; hence different dissections are necessary in order to expose them. Thus, from the face and left limbs, the integuments only are supposed to be removed, so that the *superficial lymphatics* are exhibited with the superficial veins resting on the fascia, or where there is no fascia, as in the face, lying on the muscles.

In the right limbs, some of the muscles are cut away to show the *deep lymphatics*, which accompany the principal blood-vessels of the corresponding parts.

In the neck also certain muscles are removed, so as to expose the deep lymphatics. The thorax and abdomen are laid open in much the same manner as in the central figure of diagram No. 4, only that the heart and its adjoining vessels, the diaphragm (all but its posterior attached border), and both kidneys, as well as the bladder, are cut away. A short piece of the small intestine is left attached by its blood-vessels to the abdominal part of the aorta.

In this way many of the deep lymphatics of the abdomen and thorax, including the main trunk of the lymphatic system or thoracic duct, which empties itself into the great veins of the neck, are here exhibited; and, moreover, that part of the absorbent system which proceeds from the intestinal canal, and serves the especial purpose of conveying a certain product of the digested food into the thoracic duct, and thence into the blood, is also illustrated.

Figs. 2 and 3 show the lymphatics upon the lungs and heart.

Fig. 4 is an enlarged diagrammatic view of the absorbents of a part of the small intestine.

Figs. 5 and 6 are highly-magnified plans to illustrate the two modes in which, as hereafter explained, the lymphatics are believed to commence,—fig. 5 being from the intestine, and fig. 6 from the skin.

Fig. 7 is an enlarged plan of a lymphatic gland.

Fig. 8 represents a section of a short piece of a lymphatic vessel, also much enlarged.

Fig. 9 is a highly-magnified view of the corpuscles and other microscopic elements of the fluid contained in and conveyed by the lymphatics, which is called *lymph.*

Figure 1.

A lymphatic system has not been detected, and may be said not to exist in any of the invertebrate animals; but it is found in variously modified conditions in all the vertebrata.

In fishes, lymphatic vessels without glands are found, and are few in number and simple in their distribution. In the batrachia and reptiles, the lymphatic vessels are more numerous, more tortuous, and often gathered together in large networks or plexuses. In certain situations too they have connected with them large dilated pouches with thick walls, which pulsate at intervals so as to drive on their contents through the vessels: these are called *lymphatic hearts.*

In the warm-blooded vertebrata, the lymphatic vessels are still more abundant, and there are superadded the little bodies called the lymphatic glands. In birds, these glands are fewer in number than they are in mammalia, including man.

In fishes, the lymphatic vessels end in, and pour their contents into many points of the venous system; but in the higher animals these points become fewer and fewer, and at length, in most of the mammalia, and in man, are restricted to the great veins at the root of the neck. Certain minute *valves* which exist in the lymphatic vessels, become more numerous as we ascend the scale of vertebrate organization,—their presence at short intervals giving rise to the jointed or varicose appearance of the distended vessels.

Lymphatics have been discovered in all the vascular tissues, and in almost all the organs of the human body,—the brain, spinal cord, and the interior of the eyeball being the only exceptions. Since their contents, whether lymph or chyle, move along them from the various parts towards the main trunk or thoracic duct, it is convenient to describe them in that direction.

Commencing everywhere by exceedingly delicate vessels, the arrangement of which will be presently described, they unite to form larger and larger vessels, until at length they assume the characters represented in fig. 1.

The *superficial lymphatics*, which are principally derived from the skin or membranes continuous with it, may be traced as numerous meandering vessels, very frequently anastomosing or communicating with one another, situated beneath the skin and upon the fascia where that exists, more especially abounding on the front of the neck and trunk and the inner aspect of the limbs, and all tending to a few particular spots near the junction of those parts with the body, where they necessarily are found in the greatest number.

Thus, those of the lower limbs and of the lower half of the trunk run towards the groins; those of the upper limbs tend towards the armpits, or axillæ. Those of the head and neck descend on each side to the root of the neck; whilst, lastly, those of the upper parts of the trunk or the thorax run some towards the armpits, and some upwards, to the root of the neck.

In these various situations, the superficial lymphatic vessels perforate the fascia, and join with deep lymphatics coming from the corresponding parts.

The superficial lymphatics become connected in certain situations, before they perforate the fascia, with a great number of the rounded bodies called *lymphatic glands*. In the lower limb, for example, these are found in the *popliteal* space or ham, on the inner side of the thigh, where they are called *femoral* lymphatic glands, *f g*, and in the groin, the *inguinal* lymphatic glands, or lymphatic glands of the groin, *g g*.

In the upper limb, they are found on the inner side beginning just above the elbow, along the arm, and especially the armpit, where they form the *axillary* lymphatic glands, *a g*. In the neck there are *sub-occipital* glands, just below the head behind, and a chain of others along the sides, called the *cervical* or *concatenate* lymphatic glands, *c g*.

The *deep lymphatics* of the head, neck, and limbs, coming from the interior of the bones, the synovial membranes of the joints, the muscles, and other soft parts, having been joined by the superficial lymphatics, as already described, pass on into the interior of the body in company with the principal blood-vessels.

Those of the lower limbs ascend along the iliac arteries and veins, where they become connected with the *iliac* lymphatic glands, *i g*, and afterwards along the aorta, where they are associated with the *lumbar* lymphatic glands, so called from their situation in the lumbar region or loins. Finally, they reach and end in the great trunk of the lymphatic system, called the *Thoracic Duct*, *r d d'*.

The lymphatics of the pelvic and abdominal viscera, with the exception of a few belonging to the liver, also end directly or indirectly in the thoracic duct,—some passing first through the iliac, others through the lumbar lymphatic glands; and so also do those of the intestinal canal (a piece of which is shown at *i*), being first connected with the so-called *mesenteric* glands, situated in a part known as the mesentery, *m*. It is by these last-named lymphatics, those namely of the intestines, that a certain fluid, derived from the digested food, is carried into the thoracic duct. This fluid, as previously alluded to, is of a milky colour, and is called *Chyle*, and hence these lymphatics are named *Lacteals* (from the Latin word *lac*, milk), and also *chyliferous*, *i. e. chyle-bearing vessels*. The lower end of the thoracic duct, which receives this fluid, is somewhat dilated, and is termed the *receptaculum chyli*, or receptacle of the chyle, *r*.

The *thoracic duct* itself, *d d'*, which may now conveniently be described, commences upon the second lumbar vertebra, and therefore in the abdomen; but soon passing through the same opening in the diaphragm as the aorta, ascends near that vessel, quite through the thorax (whence its name), resting on the vertebral column, and finally, having reached the left side of the root of the neck, behind the great veins, bends down again, as shown at *d'*, and opens by a valved aperture into the point of junction of the great veins of the neck and upper limb called the left jugular and left subclavian veins, so as to pour its contents into the venous current as it is pursuing its way to the right side of the heart.

The lymphatics of the left half of the chest,—including those of the left lung and of part of the heart,—likewise those of the left upper limb, and left half of the head and neck, find their way at different points, higher and higher up, into the thoracic duct.

There remain, therefore, of the lymphatics of the entire body, only those of the right half of the thorax, the right upper limb and the right side of the head and neck, to be traced into the venous system. These, together with a few from the upper surface of the liver, unite, at the right side of the root of the neck, into a trunk of considerable size, though much smaller than the thoracic duct, called the *right lymphatic duct*, which ends in the angle formed by the meeting of the right jugular and right subclavian veins. It should in the last place be mentioned, that a few scattered lymphatic vessels end at once in the great veins at the root of the neck. With such slight exceptions, the lymph from the body generally, and the chyle from the intestines, enter the blood-stream, partly by the right lymphatic duct, but principally by the thoracic duct.

Figures 2 and 3.

The viscera are provided with lymphatics as well as the other vascular tissues of the body. They are arranged in *superficial* and *deep* sets, the former on the surface and the latter in the interior of the organs.

Fig. 2 shows the superficial lymphatics of the right lung, *l*, the bronchus, *b*, and the trachea, *t*. The lymphatic glands on the bronchi, called *bronchial* lymphatic glands, *b g*, are generally coloured with a pigment, like that found in the lungs.

In fig. 3, the pulmonary artery is removed above its semilunar valves. The great veins are cut close to the auricles. The right auricle and ventricle are marked *a* and *v*; the left, *a'* and *v'*. The lymphatics are seen on the heart and on the aorta, *b*.

Figure 4.

This figure represents a portion of the small intestine, marked *i i*, together with a double fold of membrane, called the mesentery, *m m*, by which it is attached to the back of the abdomen, and between the two layers of which the blood-vessels, lymphatics, and nerves pass to or from the intestine.

In the central figure, 1, nearly corresponding parts are shown, the intestine being also marked *i*, and the mesentery, *m*.

In the present figure, on a larger scale, the lymphatics, or, as they are here called, from their milky-white contents during the absorption of the digested food, the *lacteals or* *chyliferous vessels*, are seen passing in all directions from the intestine on to the mesentery, where they become connected with lymphatic glands, *m g*, which are here called the *mesenteric* glands. Beyond these glands, the lacteal vessels pass along within the mesentery, in company with the blood-vessels and nerves, and finally enter the dilated lower end of the thoracic duct, called the receptaculum chyli, *r*, fig. 1.

In slain animals, and even in the human body, examined soon after death inflicted whilst the absorption of chyle is going on, the lacteal vessels on the small intestine and mesentery may be readily seen as delicate opaque white lines, and the thoracic duct is then found to contain a milky-looking fluid, which soon turns pinkish on exposure to air. But during the intervals in which no chyle is being absorbed, the lacteals are invisible, and convey only a transparent lymph, like the lymphatics of any other part of the body, which, indeed, they entirely resemble in their general characters and structure.

Figures 5 and 6.

Of these figures, which illustrate the mode of commencement of the absorbents, fig. 5 is a plan magnified 300 times, exhibiting their supposed mode of origin on the internal or mucous surface of the small intestine. This surface, as shown in diagram No. 6, figs. 11 and 12, each of them much enlarged, is covered with little soft processes, about $\frac{1}{40}$th to $\frac{1}{30}$th of an inch in length, which are so numerous and closely set as to give the surface, when floated under water, an appearance like the pile on velvet. Hence they are termed *villi*, and the mucous membrane on which they are found is named a *villous* mucous membrane. Fig. 11 of that diagram shows a surface-view of a piece of the intestinal mucous membrane, whilst a section, more highly magnified, is given in fig. 12.

In the centre of each villus, as shown in fig. 5 of the present diagram, is a single lymphatic vessel or *lacteal*, *l*, surrounded by the proper tissue of the villus, and by a network of capillary blood-vessels, *v*, much smaller than the lacteal vessels,—the whole being invested by an outer skin, called the *epithelium*, *e*.

According to some microscopical observers, each lacteal commences near the tip of its villus by a club-shaped dilatation; but, according to others, by an irregular network. Be this as it may, the little central lacteals from the myriads of intestinal villi enter a common plexus or network of larger vessels, situated at their base, from which, again, still larger lacteals pass towards the outer surface of the intestine, and there end in the more obvious vessels already described, and represented in fig. 4.

On smooth surfaces, such as those of the pleura, pericardium, and peritonæum, on non-villous mucous membranes, and on the skin, the lymphatics arise by a network or plexus, so close in some cases, as, when filled with mercury, to cover the entire surface.

Fig. 6 serves to illustrate this the common mode of origin. It shows the injected lymphatic network or plexus on a portion of skin; its position being beneath the non-vascular cuticle, and within the vascular skin or dermis.

The figure is enlarged about 35 diameters.

The deep-seated lymphatics, arising in the substance of the muscles or of other organs, are fewer in number, and probably commence by a network also.

The size of the commencing lymphatics varies much; but they are in all cases larger than the capillary blood-vessels, and in no circumstances do they communicate with them.

Figure 7.

This is a large diagrammatic view of a lymphatic gland, together with portions of lymphatic vessels connected with it,—both gland and vessels being supposed to be injected with mercury.

The jointed or varicose form of the vessels, when distended, is well seen.

Those which, as indicated by the arrows, enter a lymphatic gland, *g*, are called *afferent* vessels, *a*, *a*, *a*; whilst those which pass out of it, like that marked *e*, are named *efferent* vessels, because, as implied by their names, they carry the lymph or chyle into or away from the gland with which they are connected.

The glands themselves, through which the fluid passes, are firm rounded or oval bodies, varying from the size of a hemp-seed to that of an almond, and surrounded by a strong investing membrane.

Their outer part consists of a number of little cells or spaces, separated from each other by imperfect septa or partitions, crossed in all directions by fine bands, and filled with a softish substance composed of corpuscles exactly like those found in the lymph or chyle, and presently to be described.

The afferent lymphatics, *a*, *a*, *a*, first dividing and subdividing, open into these cells or interspaces, whilst from them other vessels pass off and form in the interior of the gland a dense plexus, which gives origin to the efferent vessels, *e*, usually fewer, but of larger size than the vasa afferentia.

The lymphatic glands are also abundantly supplied with blood-vessels, which ramify in their interior, but do not communicate directly with their lymphatic plexuses or cells.

Figure 8.

The walls of the smallest or commencing lymphatics and lacteals probably consist of only an homogenous membrane; but in the larger ones, and in the thoracic duct, the coats are composed of areolar, elastic, and involuntary muscular fibres variously disposed, and of an internal lining epithelium. They resemble in this respect the finest veins, but are altogether much more delicate and quite transparent.

Those which attain a certain size have, in their interior, a number of valves placed at close intervals, and giving rise to the jointed appearance of the vessels so often alluded to.

These valves exist in various degrees of development, but when perfect, they consist, as shown in fig. 8, which is a section through several joints of a lymphatic, of a pair of exceedingly delicate transparent semilunar folds, the free edges of which are turned towards each other in a direction corresponding with that in which the contained lymph is to move, *i. e.* towards the termination of the vessel in question.

The thoracic duct has many such pairs of valves in its course: and both it and the right lymphatic duct are provided with them at their entrance into the venous system.

The office of these valves, like those in the veins, is to secure the transmission of the lymph or chyle in a determinate direction on towards its destination in the great veins at the root of the neck; for whatever causes may give rise to motion in the contained fluid, must in the aggregate operate in the direction permitted by these internal valvular folds,—as is indicated by the arrows in this figure.

Figure 9.

The lymph found in the absorbent vessels, is a clear transparent fluid, containing a few pale microscopic spherical corpuscles, having a nucleus in their interior, and as seen in the figure, exactly resembling the colourless corpuscles of the blood. These corpuscles most abound in the lymph which has passed through one or more lymphatic glands. The lymph also contains a few smaller granular particles and but rarely some oil globules. The chyle, which, as already mentioned, is a milky-looking fluid, likewise contains the same sort of pale corpuscles, but is especially characterized by a large quantity of *fine molecules*, which appear to be of a *fatty* nature, some oil globules, minute particles of an albuminous nature, and some free nuclei.

The fluid portion of both chyle and lymph contains a small portion of fibrin, albumen, and salts. It is therefore like the liquor sanguinis, and will feebly coagulate, but it is much more aqueous or dilute. The quantity of fibrin in it increases after the lymph has passed through the lymphatic glands.

From the microscopic and chemical constituents and ultimate destination of these fluids, it is evident that they are intended to supply materials for the formation of new blood, and it is the office of the lymphatic and lacteal vessels to *absorb*, *convey*, *elaborate*, and empty into the venous system those nutritive materials.

The chyle is evidently derived from the digested food, in a manner which will be explained in the account to be given of diagram No. 6, relating to the digestive organs. The lymph has, however, a more obscure origin.

It would seem that, when the liquor sanguinis, or fluid colourless part of the blood, has traversed the thin delicate walls of the capillary vessels, so as to bathe and nourish the various tissues and organs, the whole of that fluid which has so exuded, is not immediately employed for the purposes of nutrition and secretion; but that a residual quantity, modified by loss of nutrient matter, according to the tissue or organ it has supplied, passes partly by imbibition into the minute veins, but partly also into the interior of the commencing lymphatics.

It is possible also that substances which have once formed parts of the tissues or organs, but which are not so far chemically changed or destroyed as to be absolutely unfit for the purposes of further nutrition, may find their way into the commencing lymphatic vessels; but of this we know nothing certainly.

It may be also that a certain balance of supply and waste is in this way maintained, especially when, as in adult life, increase or growth is arrested. And furthermore, it is possible that certain processes of absorption of the tissues which take place in the body in health or disease, as in the giving way of the gum for the passage of the cutting teeth, in the absorption of parts from the pressure of tumours or the application of ligatures, and in certain losses of substance on the surfaces of membranes, may result, in part at least, from the action of the lymphatics. But here again exact knowledge is still required, and doubtless such processes may be conceived to take place independently of such vessels, as in the invertebrate animals, which do not possess them.

As to the mode in which the lymphatics and lacteals absorb their proper fluid, very little also is known. It is partly, no doubt, by simple imbibition throngh their excessively delicate coats; but it is almost evident, that, in the case of the lacteals, and by inference in that of the lymphatics generally, there is an elective process, so to speak, exercised at their commencements, which insures the admission into their interior of only certain materials proper to form chyle or lymph.

It is certain, at any rate, that many soluble and excrementitious substances, which are wholly unfit for nutrition, and which must come within their range, do not readily, if at all, enter them. They have, in this respect, a marked superiority over the finest veins and the capillaries nearest to them, which speedily absorb by imbibition hurtful and even poisonous substances which are in a state of solution. Certain morbid animal products, such as those of small-pox, vaccine lymph, pus and perhaps cancer, appear, however, to be absorbed by the lymphatics.

The use of the lymphatic glands is evidently to elaborate more highly, and so prepare for entrance into the blood, the lymph and chyle which pass through them; for those fluids, as already mentioned, abound more in their chemical and microscopic elements and so approach more closely to the blood in their composition, after they have passed through some of these glands, where they must move more slowly than along the simple vessels. In certain cases, in which these glands are said to be sympathetically inflamed, they become enlarged, and may even suppurate or form abscesses,—as if apparently there were some effort to arrest an injurious product, or to cast it out of the system by the formation of matter. Examples of this sometimes occur in the sub-occipital glands from eruptive diseases of the scalp, so common in sickly children, and in the glands of the armpit or groin, from a dissection or other poisoned wound, or whitlow on the hand, or from a chafed or abraded sore on the foot.

The glands of the neck are a favourite seat of scrofulous deposit and enlargement.

The causes of the onward movement of the chyle or lymph are not well understood; but besides that imperceptible though powerful agency which would result from their supposed organic property of selecting certain fit substances for admission into their interior, it must be remarked that the coats of these vessels, above the very smallest in size, are all provided with involuntary muscular fibres, having a slow contractility.

The distended lacteal vessels watched in an animal recently slain may be seen slowly but steadily to empty themselves, doubtless by virtue of this contractility set in action by the stimulus of cold on exposure to the air.

In the case of the lacteals too, the contractions and movements of the intestinal walls, and in the case of the lymphatics generally, the various movements of the muscles of the body, must, by subjecting them to pressure, impart motion to their contents; and by the admirable provision of their countless valves, that motion must always be towards the entrance of the two great trunks of the entire absorbent system into the veins at the root of the neck.

Here, regurgitation being effectually prevented, also by valvular structures, the lymph, and, after digestion, the lymph and chyle, are gently and slowly poured into the blood, not against but with the current of that fluid towards the heart, owing to the bending downwards of the two great lymphatic trunks. Next, whirled along the veins to the right side of the heart, it is there churned, as it were, and intimately blended with the blood in the right auricle and ventricle. Thence, the perfect mixture is sent on through the great oxygenating and purifying organs,—the lungs—and becomes fit to proceed through the left side of the heart, the aorta, and systemic arteries, to all parts of the body.

No. 6.—The Digestive Organs.

◆

The digestive process, namely that by which food is converted into a fit material to be absorbed into the system, is so complicated a function, and in man and the higher animals is performed by the aid of so many organs, that it differs in this respect remarkably from the functions of absorption, circulation, and respiration, the parts concerned in which present much less variety.

The simplest form of digestive apparatus found in any animal consists of a *sac*, formed in the interior of the creature, and having a single opening, which serves both as inlet and outlet. Such a sac, or true *stomach*, the essential part of every digestive apparatus, exists in the little green fresh-water polype, named the hydra; and so identical in character is its lining membrane with the skin,—with which it is continuous at the single opening or mouth,—that if the animal be turned inside out, the inverted integument, now become the lining membrane of the sac, is equally capable of performing the digestive process.

There is another lowly-organized creature, an infusorial animalcule called the amœba, which has no internal cavity at all, but simply wraps the soft substance of its body over any digestible object, and acting in some way upon it, absorbs the nutriment from it, and then disengages itself from the residual mass.

In a higher form, but still in the invertebrate animals, the digestive apparatus consists essentially of a hollow membranous *tube* having a separate inlet and outlet,—the one for the entrance of food, the other for the escape of indigestible matter. This is called the *digestive tube* or *alimentary canal.* One part of it, more dilated than the rest, which may be termed the *stomach*, has poured into it certain *solvent juices*, which, formed or secreted by little glandular follicles, operate chemically upon or *digest* the food.

In some cases there is superadded an apparatus for crushing, bruising, or otherwise acting mechanically upon the alimentary substances.

In all these instances, the prepared nutrient material is absorbed directly into the tissues or blood-vessels of the animal, through the walls of the alimentary canal, there being no lymphatic or lacteal vessels for that purpose.

In the vertebrate creatures from fishes upwards, the digestive apparatus is much more highly complicated. By some, as in certain fishes and birds, the food, after being seized and swallowed, is passed at once into the dilated part of the alimentary canal or stomach, where it undergoes digestion, either with or without the aid of a process of trituration by an internal apparatus, such as the gizzard of birds. Much more commonly, however, after having being first seized by some *Prehensile* organs, the food is received into a part called the mouth, and there by the agency of teeth set in movable jaws, is more or less bruised or torn,—a process which is called *Mastication*. Within the mouth too, it becomes moistened and mixed with mucus and saliva,—fluids secreted by the salivary and other glands, —thus undergoing what is termed *Insalivation*.

From the mouth, the alimentary mass is conveyed by muscular power through parts called the throat and gullet into the stomach, by what is termed the act of *Swallowing* or *Deglutition*.

In the stomach, a sort of dilated pouch, it is for a time arrested and subjected to the action of the *gastric juice*, a fluid secreted by the walls of that portion of the alimentary canal, and thus undergoes *Digestion proper*.

By these processes the parts capable of being acted upon or dissolved are converted into a pulpy substance, varying in colour according to the food, and called *chyme*,—this part of the digestive process being therefore also termed *Chymification*. Passing now out of the stomach into the succeeding and narrower part of the alimentary tube, which is known as the intestinal canal, or intestines, the chyme becomes mixed with the *bile* secreted by the liver, and with the *pancreatic juice* formed by the pancreas or sweet-bread; and from this mixture there results, among other products, the white milky-looking emulsion named *chyle*. This, the final stage in the process, is called *Chylification*.

The chyle, which contains the real nutritive substances of the food prepared and fitted to enter the animal tissues, is absorbed by the *lacteal vessels* of the small intestines, and conveyed by the thoracic duct into the blood, in the manner pointed out in the description of the last diagram. The residual mass, together with certain intestinal fluids, passes along the great intestine and is expelled as unfit for absorption into the system.

In the present diagram, the following very numerous parts of the human body concerned in this complicated function are displayed.

Figs. 1 and 2 illustrate the form, structure, and order of growth of the *teeth*.

Figs. 3 and 4 exhibit, the one a sectional view of the head and neck, the nose, mouth, and parts lying in the *throat*, and the other a hinder view of the throat or swallow. They serve to assist in explaining the act of *deglutition*, and the parts concerned in it.

Fig. 5 is a plan of that portion of the alimentary canal which occupies the cavity of the abdomen, here shown as if removed from the body and rather fully distended. In it are seen the dilated portion or *stomach*, *s*, and the succeeding long part, named the *intestines*, consisting of the *small intestine* from *d* to *i'*, and of the *large intestine* from *c* to *r*. This figure is quite diagrammatic.

Figs. 6, 7, 8, illustrates the microscopic structure of the inner coat of the stomach, or *gastric mucous membrane*, showing the little *tubular glands*, *a b*, which secrete the gastric juice.

Figs. 9 and 10 show the several coats of the small intestine, and certain *valvular folds*, *v*, in its interior, by which its internal absorbing surface is so much increased in extent.

Figs. 11 and 12 show the minute structure of the inner or mucous coat of the small intestine, its little processes called *villi*, its open *tubular glands* or *follicles*, *f*, and its closed glands, *g*, called *Peyer's glands*. This is from the calf.

Fig. 13 is a diagrammatic plan of a section through the middle line of the body, to show that remarkable arrangement of the blood-vessels of the abdominal organs of digestion, which has received the name of the *Portal Circulation.*

Fig. 14 is a plan of the neck, chest, and abdomen, laid open to show a deeper view of certain parts of the digestive apparatus;—for example, the *throat* or *pharynx*, *p*, the *gullet* or *œsophagas*, *o*, the *stomach*, *s*, the upper part, *d*, and lower end, *i*, of the *small intestine* (the rest being cut away), the *large intestine*, *c* to *r*, the *liver*, *ll'*, and *gall-bladder*, *g*. It also shows an organ called the *spleen*, *m*.

Fig. 15 illustrates the mode of formation of the constricted part, or circular valve, called the *pylorus*, at the junction of the stomach with the small intestine.

Fig. 16 represents the termination of the small intestine in the large intestine, and the *valve* situated at that point.

Fig. 17 shows the *liver*, *ll'*, the *gall-bladder*, *g*, and the *stomach*, *s*, *turned up* so as to exhibit their under surfaces, and at the same time to display at the commencement of the small intestine called the *duodenum*, *d*, the gland named the *pancreas*, *b*, and also the *spleen*, *m*.

All these figures are to be regarded as plans rather than fac-simile representations of the parts in question. The tints employed are also in a great degree conventional, or at most, approximations to the natural colours of the organs represented. Moreover, it may be observed that these seventeen figures exhibit detached parts, the position and connections of which in the body are shown in other diagrams of the series, especially in No. 3, which is accordingly recommended to be displayed with the present one.

After these explanations we may proceed to describe the digestive organs of man under the following heads:—

The Mouth, including the Tongue, the Salivary Glands, and the Teeth. The Throat and Gullet. The Stomach and Intestinal Canal. The Liver, with the Gall-bladder and the Pancreas. The Spleen.

Figures 1 to 4.

The Mouth, including the Tongue, the Salivary Glands, and the Teeth.

The Mouth.

The cavity of the mouth extends backwards from the *lips* to the arched opening named the *fauces*, which is seen over the back of the tongue, on looking into the throat. The sides of the mouth are formed by the *cheeks*, the roof by the *palate*, and the floor by the *tongue*. (See fig. 3.)

The cheeks and lips consist of certain muscles already noticed (see diagrams Nos. 2 and 3), of a layer of skin outside, and of the mucous lining of the mouth within,—the two membranes becoming continuous with and changing into one another at the borders of the lips. Besides the intervening muscular tissue, there are found fat, mucous glands, vessels and nerves.

Together with the cheeks, the lips,—especially the lower lip,—serve to retain the saliva and mucus within the mouth,—an office the importance of which is proved by the distressing escape of those fluids in cases of paralysis or of loss of substance of the lower lip, or of the dragging down of that part from scarring of the neck after burns. By means of their muscles, the lips are enabled to seize, compress, or suck various kinds of food, and also to adapt themselves accurately to the borders of drinking-vessels, and so to guide liquids on to the tongue.

In the acts of insalivation and mastication, the lips and cheeks are also most actively employed, either in retaining food between the teeth or in changing its position; and they also assist in forcing the saliva and mucus into the interstices of the alimentary mass.

The roof of the mouth or *palate* is partly hard and partly soft. The anterior or *hard palate* is formed by the upper jaw-bones and the palate-bones, covered by a dense mucous membrane, which adheres firmly to the periosteum of those bones, and is continuous with the upper gums. The hinder part or *soft palate* is a pendulous fleshy curtain, continuous with the hard palate, and hanging down at the back of the mouth. Its lower edge is free, and forms a sort of arch, from the centre of which depends a small soft projection called the *uvula*. Beneath the arch is the opening of the *fauces*, already mentioned as leading into the throat. The soft palate is composed of two layers of mucous membrane, continuous with one another round its lower border, and having (besides fat, glands, vessels, and nerves) many muscular bundles between them. These muscles, which act on it in various directions, raise it, lower it, tighten it across the fauces, or draw its two halves aside, so as either to close or open the aperture leading from the mouth into the throat.

The entire palate effectually serves to separate the mouth from the nose, and during the acts of eating or drinking, prevents the food or fluid from passing up into that cavity. The hard palate also presents a resisting surface, against which the tongue presses the food, and insures its more perfect contact with the parts endowed with taste. Whilst mastication is being performed, the soft palate closes the mouth behind; but its most striking office is in the act of deglutition, to be presently described.

The *tongue* is a muscular organ, supported beneath by a small bone called the *hyoid bone*, fig. 3, *h*. It is also attached to the lower jaw-bone, to certain long processes of the temporal bones, and also to the lower part of the arch of the fauces. Of its *muscular fibres*, some ascend from the hyoid bone, others spread out from that part of the lower jaw situated just behind the chin, some pass down from the processes of the temporal bones, a few descend from the soft palate along the side of the fauces, and lastly certain intrinsic muscular fibres run some lengthways, and others transversely in the substance of the tongue itself. This organ is, therefore, very movable, and is capable of undergoing remarkable changes in position and form. Its upper surface is roughened by numerous little elevations called *papillæ*, which will be described hereafter under the Organ of Taste. (See diagram No. 8, figs. 10 and 11.)

In the act of drinking, the tongue guides the liquid in the direction of the throat. In mastication, it is constantly engaged, together with the cheeks, in the important mechanical office of keeping the food between the jaws, and at the same time turning it over and over, so that fresh parts are submitted to the action of the teeth; by it also the food is transferred at will to one or other side of the grinding apparatus. The roughness of its surface, its extreme flexibility combined with power, and the great freedom and variety of its movements admirably adapt it to these purposes. It also compresses the food against the palate, helping thus to mix it with saliva, and to extract flavour from it. Lastly, the tongue is employed in the act of sucking, being drawn down backwards as if to create a vacuum, as may be watched in infants.

The *mucous membrane* of the mouth, moist and red, covers every part of it excepting the teeth, to the necks of which, however, it adheres. By its reflection from the lower gums on to the sides and under-surface of the tongue it supports that organ, and presents beneath the tip, a well-marked fold called the *frænum*, which when too much developed, produces what is called *tongue-tie*. It also serves in a similar way by its reflection to connect the lips and cheeks with the arches of the jaw-bones. It is thin, delicate, and smooth, within the cheeks and lips, beneath the tongue, and on the under-surface of the soft palate;—denser and thicker, and provided with minute and concealed papillæ on the free borders of the lips, on the gums and on the hard palate;—thick, and as just mentioned, covered with obvious projections or papillæ on the back and edges of the tongue. Its epithelium is throughout of the squamous kind (see diagram No. 9, fig. 75), arranged in many layers.

The mucous membrane of the mouth is provided with *glands* of two kinds. One set secretes the mucus which constantly moistens the mouth, sheaths and protects its surface against irritating substances, and serves specially also to lubricate the food about to be swallowed. They consist of numerous little lentil-shaped bodies called *conglomerate* glands, such as are described in diagram No. 9, fig. 67, *g*. Their excretory ducts open into the mouth. They exist in clusters, inside the lips and cheeks, beneath the borders and at the back part of the tongue, and on the under-surface of the soft palate, being named respectively the *labial*, *buccal*, *lingual*, and *palatal* mucous glands. The glands of the other kind are without ducts; they are found at the root of the tongue, and consist of small narrow-mouthed recesses, having numerous microscopic closed sacs embedded in their walls. Their use is not known, but they are supposed by some to be connected with the lymphatic system.

The Salivary Glands.

The *Salivary glands* which secrete the saliva, are placed in the immediate neighbourhood of the mouth, and are three in number on each side; viz. the *Parotid gland* (shown in diagram No. 4, fig. 1, *s*), so called from two Greek words, παρὰ ὠτὶ *(para oti)*, signifiying near the ear; the *Sub-maxillary gland*, placed beneath the lower jaw, and partly seen in the same figure; and the *Sub-lingual gland*, situate in the mouth, where it forms a projecting ridge along the underside of the tongue. The parotid is the largest, and the sub-lingual the smallest of these glands.

Each consists of a congeries of parts called *lobes*, themselves composed of smaller parts called *lobules*, all being held together by areolar tissue, blood-vessels, and little membranous tubes belonging to the glands called *ducts*. Each lobule consists of a branching tube, which ends in a bunch of minute terminal *vesicles*. See diagram No. 9, fig. 70, which is a representation of a small portion or lobule of the parotid gland, injected with quicksilver and highly magnified. These vesicles, about $\frac{1}{1000}$th of an inch in diameter, have capillary blood-vessels upon their walls; and from the blood thus supplied, the saliva is secreted into the interior of the vesicles, whence it passes into the branched tubes. By the junction of the branched tubes from various lobes with one another, a principal efferent tube or duct is formed, through which the saliva is conveyed into the mouth.

For the parotid gland there is a single large duct, named after an anatomist, the *Stenonian duct*. As shown in diagram No. 4, fig. 1, it pierces the buccinator muscle, 10, and opens on the mucous membrane of the mouth opposite the second upper molar tooth, just where the food is chiefly masticated. The sub-maxillary gland also has a single duct, named the *Whartonian duct*, which opens on the floor of the mouth, close to the frænum of the tongue. The sub-lingual gland is rather a mass of little glands, for it has many ducts, opening either into the Whartonian duct, or separately beneath the tongue along a ridge seen between it and the lower jaw.

The secretion from the six salivary glands flows into the mouth therefore at many points. In the intervals between taking food, these glands are nearly quiet, but during mastication, many ounces of saliva are poured into the mouth. It is said that upwards of fifty ounces are formed in twenty-four hours. The increased activity of the secretion, during eating, which implies an increased flow of blood into the gland, is chiefly regulated through the nerves.

Without any food entering the mouth, the sight or even the thought of it, will, to use a common expression, cause the mouth to water. The muscular movements necessary to the act of mastication attract blood to the parts about the mouth, and thus co-operate in the desired increase of secretion; whilst they also serve to press or squeeze it from the ducts into the cavity of the mouth. If indeed the mouth be opened before a looking-glass, and the tongue be suddenly turned up towards the roof, drops of saliva will often be seen to be ejected from the little openings in the ducts of the two sub-maxillary glands which are visible on the small eminences at the sides of the frænum or string of the tongue.

The *saliva* itself is a limpid, alkaline fluid, containing only one part of solid matter to 200 parts of water, and holding in solution or suspension a peculiar animal substance called *ptyaline* or *salivine*, with a few earthy and alkaline salts, amongst which is the sulpho-cyanide of potassium. It contains a few microscopic corpuscles. The saliva secreted by the sub-maxillary gland is viscid, and contains more solid matter. The uses of the saliva are partly mechanical and partly chemical. It serves to moisten and cleanse the mouth and moderate the feeling of thirst, and it or some other moisture is absolutely indispensable for the exercise of the function of taste; but its special mechanical office is to soften the food, and to render mastication and deglutition easy; whilst at the same time it prepares the alimentary mass for thorough percolation with the gastric juice. It is also a powerful solvent,—no doubt acting in this way upon many nutrient and sapid substances. Chemically considered, the saliva, aided also by the mucus of the mouth, possesses the remarkable property of transforming starch into a kind of sugar, and this sugar into lactic acid. Whether, as is possible, it acts chemically on other substances is not known. It is evident, however, that the process of *insalivation*, which takes place simultaneously with mastication, is one of high importance. For its due performance, a certain quantity of food requiring trituration by the jaws, should always be taken at meals, and this should be well masticated before it is swallowed.

The Teeth.

The *Teeth* are the essential organs of *mastication*, but the apparatus employed for this purpose includes the dental arches of the upper and lower jaws, in which the teeth are lodged, and the various muscles which move the lower jaw upon the upper, which, it may be remembered, is fixed to the rest of the skull.

The *joints* formed on each side by the lower jaw with the temporal bones, are loose hinge-joints, and are the seat of the various movements of the lower jaw up or down, to or fro, and from side to side, during mastication.

The aperture between the teeth is opened partly by the weight of the lower jaw, but chiefly by proper *muscles* situated below it. These are the *digastric* muscle, diagram No. 2, fig. 1, 12, 12, of each side, and certain muscles which pass up towards the back of the chin from the hyoid bone (see fig. 3 in the present diagram), which little bone is itself drawn down or held in position by such muscles as the *sterno-hyoid* and the *omo-hyoid*, 13 and 14, fig. 1, diagram No. 2. The principal muscles which raise the lower jaw and shut the teeth with such extraordinary force, are the *temporal* and *masseter* muscles, marked respectively 2 and 11 in the same diagram. There are also two strong co-operating muscles concealed by the upright parts of the lower jaw-bone. These latter also aid in the slight backward and forward, and side to side movements of the jaw, which take place during mastication, and so materially help to triturate the food, which is kept in position by the *buccinator* muscles, 10, one each side, aided by the tongue.

The *teeth* are thirty-two in number, that is, sixteen in each jaw,—eight on each side of the middle line.

Commencing at that line as shown in diagram No. 1, fig. 2, there are first *two* straight-edged *incisor* or *cutting teeth;* then *one* pointed *canine* or *dog-tooth;* next *two* double-pointed *bicuspid* or *small molar teeth;* and lastly *three* square-topped and many-pointed *large molars* or principal grinding-teeth. There are accordingly four kinds of teeth, which are repeated in each half of the two jaws to make up the number thirty-two.

Each tooth consists of an exposed part or *crown*, and of an elongated concealed part called the *fang* or *root*, the constricted part between them, to which the gum is fixed, being named the *neck*.

The *forms* of the different teeth are shown in fig. 1. The incisor teeth, as at *i*, have crowns bevelled behind, and ending in a straight sharp edge, which, when not worn by use, is slightly jagged: they have a single conical root or fang. The canine teeth, *c*,—so called because in dogs and, it may be added, in the carnivora generally, they are large and prominent,—have crowns ending in a point or cusp (whence they are named cuspidate teeth), and often presenting a small tubercle near the neck behind; the fang is single, but longer and wider than the incisor fang, and grooved on the sides; the upper canines, also called the *eye-teeth*, are larger than the lower ones. The bicuspid or small molar teeth, *d*, have broad two-pointed crowns, whence their name; the fangs, shorter than the canine fangs, are grooved in the lower, but double in the upper jaw. The large or proper molar teeth, *m*, have still broader and squarer crowns, terminating in four or even in five cusps or summits; they have either two broad fangs, each grooved as if for further subdivision, or as in the first and second upper molars there are three wide-spread fangs: the first molars are the largest teeth in the head; in the last molars or wisdom teeth, both above and below, the fangs are more or less coalesced.

The teeth are chiefly composed of a peculiar substance, somewhat resembling bone, called *dentine*, but the whole of the crown, which is constantly exposed to wear, as low down as the neck, is protected by a closely adherent hard polished bluish-white substance, named the *enamel.* (See diagram No. 9, fig. 28.) The fang also consists of dentine, but (after a certain period of life) it is covered by a very thin layer of true bone, called here the *cement* or *crusta petrosa.* The *tartar*, which often gathers round the necks of the teeth, is merely a deposit of earthy salts, apparently derived from those contained in the saliva, and mixed with the remains of microscopic algaceous growths.

The relative extent and position of the dentine and enamel in an incisor and a molar tooth are seen in the sections *i'* and *m'*, which also show the existence, in the centre of the teeth, of a cavity which is prolonged down to the very point of each fang. This is called the *pulp-cavity*, because during life it contains a soft papilla named the *tooth-pulp*, well supplied with blood-vessels and nerves which gain access to it by passing from the tooth-sockets through small openings at the points of the fangs. This pulp, so necessary to the preservation of the vitality of the tooth, is prone to inflame, especially when exposed by decay of the tooth-substance or enamel; and then it gives rise to tooth-ache, which is really a pain in the nerves of the tooth-pulp, or in those of the lining membrane of the tooth-sockets to be presently mentioned.

The mode in which the teeth are fixed in the jaws displays the most admirable design. The fangs are received as far as the necks into corresponding sockets called *alveoli*, formed in the maxillary bones (see fig. 2). The conical form of the fangs, and their nice adaptation to their sockets, serve to diffuse any pressure made upon the crowns nearly equally over the surface of the fangs and sockets, in such a way too as to protect the points of the fangs where the nerves enter. It must not be supposed, however, that the hard fang is in actual contact with the hard socket, like a peg or nail in a piece of wood; for everywhere between them is interposed a fibro-vascular or *periosteal* membrane, which not only organically connects them, but also forms a bed or cushion, effectually deadening all shock or violence during the use of the teeth in the healthy state, but which may become the seat of pain when it is inflamed.

The human teeth, and indeed the teeth of animals, are not, as one might have believed, from their hardness and their bony nature, parts of the internal or *endo-skeleton*, but they belong to the tegumentary system or *dermo-skeleton*, which includes, speaking generally of man and animals, the teeth, nails, hoofs, horns (not antlers), scales, and hairs. The mode of *origin* of the teeth proves this; for though in man and in mammiferous animals they are developed in little *sacs* beneath the soft parts of the jaws, and subsequently grow up through the gum, yet these little sacs themselves are at an early date *open follicles*, or depressions in the mucous membrane covering the rudimentary jaws, which follicles subsequently becoming closed, form the *tooth-sacs.* From the bottom of each of these sacs, springs up a little soft *vascular* and *nervous papilla*, in the surface of which,—when it has attained a certain stage of growth,—by a process of conversion of its substance, the dentine is formed; whilst at the same time a coating of enamel derived from a membrane occupying the upper part of the sac, spreads over the newly-forming dentine. The papilla having its characteristic shape for each tooth, the dentine and enamel follow that shape, and go on being formed, until the tooth advancing to perfection approaches the surface of the gum, causes absorption of this by pressure, and finally appears through it, or is *cut.* Additional dentine still continues to be produced so as to lengthen and complete the fang or fangs; the elongated papilla now becomes the tooth-pulp, and the tooth itself is protruded above the gum as far as its neck.

Man, like the mammalia generally, has two sets of teeth, the *milk-teeth* which sooner or later are shed, and the *permanent teeth.* The milk-teeth are twenty in number, ten in each jaw, five in each side of the middle line,—as shown in fig. 2, which is the half of the lower jaw, seen from its outer side. They consist, beginning in front, of *two incisors,* fig. 2, *i, one canine, c,* and *two molars, m.* There are no bicuspids in this set; and it must be carefully noted that the third molar tooth seen in the figure is not a milk-tooth, but one of the permanent teeth, viz. the first molar, which is cut before the shedding of any of the milk-teeth. Of the milk-teeth, the middle incisors are usually cut at about the age of seven months, the lateral incisors at nine; the first molars at twelve, the canines at eighteen, and the last molars at twenty-four months. The times vary, but the order seldom does. The lower teeth precede in appearance the corresponding upper ones. A very late appearance of the milk-teeth is one of the signs of defective nutrition, and should be regarded by parents accordingly. The permanent teeth are also formed in sacs, derived from extensions of those of the milk set. Their position and stage of growth at the age of six years and a half are shown in fig. 2. All but the first molars lie buried deeply in the bone behind the milk-teeth, which are perfect at that date. The two growing permanent incisors are marked, *i′*, the canine tooth, *c′*, and the two bicuspids, *b′*. The first molar, as already mentioned, has risen through the gum, just beyond the last milk-tooth,—the second molar, still buried in the jaw, is marked *m′*, whilst the sac of the third molar or wisdom-tooth, so late in appearing, contains as yet no trace of any tooth-substance.

As the permanent teeth grow and their fangs become elongated, their crowns press up on the roots of the milk-teeth above, which undergo absorption, lose their hold and are *shed.* The permanent teeth rise up and occupy their places; and in a regularly formed human jaw, form an unbroken row, the necessary additional space being provided for them by the cotemporaneous enlargement of the bone. In all animals the teeth form interrupted rows. The order and approximate times in which the human permanent teeth are cut, are as follows, those of the lower jaw preceding those of the upper:—First molars at six and a half years; central incisors at seven; lateral incisors at eight; anterior bicuspids at nine; posterior bicuspids at ten; canines at eleven and twelve; second molars at twelve to thirteen; and the last molars or wisdom-teeth at from seventeen to twenty-five years.

Hard, well-fixed and beautiful as are the so-called permanent teeth, their permanency after all is but relative, and their absolute duration brief. Exposed to injury and disease they break or decay; and even if they escape such accidents, they gradually wear down at their summits, get absorbed at their fangs, and in time drop out,—affording one amongst the many signs of the limits placed by Providence to the endurance of the human organization, and the length of human life.

The mouth and its contents, besides being employed in mastication and insalivation, are,—cheeks, lips, tongue, palate, gums, and teeth,—all more or less concerned in speaking and singing. The salivary and mucous glands play an important part in these acts, for a certain amount of moisture in the mouth is quite indispensable for the production of articulate speech and song.

Figures 3 and 4.

The Throat and Gullet.

The food having been converted, by mastication and insalivation, into soft morsels fit for deglutition, is in the next place swallowed; and the parts which it passes through, on leaving the mouth, are the arched passage beneath the soft palate named the *fauces*, the *pharynx* or bag of the *throat*, figs. 3 and 14, *p*, and the *œsophagus* or *gullet*, *o*, from which it enters the stomach, fig. 14, *s*.

The opening of the fauces, so easily seen in the living person, is bounded on each side by two folds called *pillars*,—one *anterior*, descending to the tongue, and the other *posterior*, which is lost on the corresponding side of the pharynx. See fig. 4, which is a hinder view of the pharynx laid open. These pillars are folds of mucous membrane containing muscular fibres, which can draw down the soft palate or close the fauces opposite either pillar.

Between the two pillars on each side are placed the almond-shaped bodies called the *tonsils*. These are glandular organs, composed of a firm tissue, containing many ramified recesses, in the walls of which are embedded little closed sacs, like those mentioned as existing at the base of the tongue. There are, besides these, numerous ordinary mucous glands ranged along the sides of the fauces, which serve to lubricate the throat and the surface of the food as it is swallowed.

The *pharynx*, or *throat*-passage, fig. 3, *p*, is a sort of bag, suspended beneath the base of the skull, and in front of the vertebral column, *v'*. It is wider above than below, and is closed above, behind, and at the sides. In front, as seen both in the sectional and hinder views, figs. 3 and 4, it communicates with the right and left cavities of the nose, *n*, lower down beneath the soft palate, marked *p* in fig. 4, through the fauces, with the mouth, and still lower with the air-passage or larynx, *l*, by an opening named the *glottis*, which is guarded by a sort of leaf-shaped valve, called from its position the *epiglottis*, *e*. Directly downwards, the pharynx opens into or rather is continuous with the *gullet* or *œsophagus*, *o*. In the upper part of the pharynx near the nose are two other openings leading to the drums of the ears, which will be hereafter explained.

The walls of the pharynx are principally muscular, consisting chiefly of three broad muscles which surround it and overlap one another, the lowest being outermost. These muscles are called *constrictors* of the pharynx, because they can compress its sides together. It has also other muscles descending from the skull, which can widen it and lift up its walls. It is lined throughout by a mucous membrane, which is of course continuous with that of the several cavities or passages opening into it—viz. with the nose, mouth, larynx, and œsophagus; but which differs at different parts, according to their physiological uses. The pharynx, it must be remembered, serves the twofold purpose of conveying food from the mouth to the gullet, and also of transmitting air from the nose and mouth into the larynx and windpipe for the lungs. The part which is on a level with the nose is used as an air-passage only, and is lined like the nose, with a delicate mucous membrane, having a ciliated epithelium (see diagram No. 9, fig. 81); but the part below this level, along which food passes as well, has a stronger mucous membrane provided with a squamous epithelium, like that of the mouth and gullet (fig. 75). It may also be remarked that the walls of the pharynx are designedly fixed to the surrounding parts in such a way, that from its upper end down as low as the orifice leading into the larynx, the cavity is habitually open for the free passage of air, whilst the lowermost portion leading to the œsophagus is more loosely attached, and its walls fall into contact with each other, except when food and liquids are passing.

The narrow musculo-membranous tube, called the *œsophagus* or *gullet*, fig. 14, *o*, which is continuous with the pharynx, *p*, descends through the neck and chest, close to the vertebral column, and therefore behind the windpipe, bronchi, lungs, heart, and great blood-vessels, and after perforating the diaphragm to enter the abdominal cavity, ends in the stomach, *s*. The walls of the œsophagus are thick, and composed chiefly of the unstriped or involuntary muscular fibres (see diagram No. 9, fig. 37), arranged in two layers,—an outer one composed of longitudinal bundles, and an inner one of circular fibres. Some striped muscular fibres are found intermixed with these, more abundantly at the upper or pharyngeal end. Within the muscular layers is a cellular coat, which supports the mucous or lining membrane. This latter is dense, provided with numerous papillæ and mucous glands, and has a thick squamous epithelium. The œsophagus is only loosely connected with the parts near which it passes, so that it easily admits of variations in width; and excepting when food and drink is passing down it, its sides are in contact,—the mucous coat being then thrown into longitudinal wrinkles.

The preceding description of the fauces, pharynx, and œsophagus includes the principal anatomical points which have reference to the offices of those parts in deglutition or swallowing. This, though a continuous act, is described as consisting of three stages, each performed by a peculiar mechanism, and having its own characteristics.

a. In the *first* stage, a given morsel of food or portion of liquid is propelled from the mouth through and beyond the anterior pillars of the fauces. This is a comparatively simple, somewhat deliberate, and entirely *voluntary* act. The muscles of the cheeks becoming tense, the tongue presses back the substance, whether liquid or solid, into the fauces, whilst the palate prevents the food or drink from going in an upward direction into the nose, as happens so distressingly when that part is defective. Those quadrupeds which possess a fleshy movable tongue, acting as just described in deglutition, have also a pendulous fleshy palate acting in the way immediately to be noticed.

b. The *second* stage of deglutition, the most remarkable and complex of the three, is accomplished by a combination of rapid and entirely *involuntary* associated movements. In it, the food or drink is conveyed through the pharynx to the œsophagus, passing by the nose above and the larynx below, the passages leading to both of which, therefore, require to be protected, or the pressure exercised on the food or drink to move them on would force them into the nasal cavities or air-tubes, and cause in the one case painful irritation, in the other violent spasm or suffocation. The onward progress of the solid or liquid mass into the œsophagus is effected by the closure upon it of the anterior pillars of the fauces, and a further backward movement of the tongue, and then by a lifting up of the sides of the pharynx, and a successive contraction of the constrictor muscles upon the descending substance. At the same time, in order to guard the nose, the posterior pillars of the fauces meet together, and, with the uvula, shut off the upper or nasal part of the pharynx from the rest: to secure the glottis, the larynx, *l*, fig. 3, is carried upwards and forwards by its own muscles, whilst the tongue following up the food, moves backwards and downwards, so that the epiglottis gets tilted back over the aperture leading into the air-passages.

In this direction also the epiglottis is forced, in the case of swallowing solid food by the morsel itself; and it may likewise be acted on by little muscular bundles connected with its edges. Moreover, the glottis, placed a little lower down, is momentarily closed by proper muscles; so that respiration is for an instant suspended during this the second stage of deglutition.

The muscles employed in the rapid and complex movements of this stage are either partially or perfectly under the control of the will; but a remarkable swiftness and precision of action is secured by making them in this instance contract together *involuntarily* under what is termed reflex nervous influence, as will be explained under diagram No. 7. In the perfection of provident wisdom, this critical act, which might otherwise, owing to the chances of suffocation, have been hazardous to life, requires no practice like the ordinary voluntary movements, but is as perfectly performed by an infant sucking for the first time, as by the most experienced person.

c. The descent of the food along the œsophagus into the stomach, constituting the *third* stage in the act of swallowing, is also entirely *involuntary*, and unless in the case of difficulty from the size or character of the mass swallowed, is accompanied with little or no sensation. The unstriped muscular fibres here concerned are not in any circumstances under the control of the will; but are excited to action by reflex nervous influence. The longitudinal fibres outside raise up and tighten the sides of the tube, whilst the internal circular fibres contract upon the food or fluid in rapid succession from above downwards, and so propel it on very swiftly into the stomach. In a horse, whilst drinking, an act which he performs against gravity, successive wavelike movements of the œsophagus are plainly seen at the sides of the neck. It is remarkable that in man, during vomiting, undulatory contractions take place from below upwards.

Figures 5 to 16.

The Stomach and Intestinal Canal.

The remaining portion of the alimentary canal, below the œsophagus, is placed in the abdomen and pelvis. It consists of the *stomach* and the *intestines*,—the latter being composed of a narrow part, called the *small intestine*, and of a wider part named the *large* intestine.

Fig. 5 is a diagram of these parts removed from the body, and somewhat fully distended with air, but so disposed as to show their shape and general connection with one another.

The dilated pouch marked *s* is the stomach,—*o*, being its upper or *œsophageal opening*, and *p*, the lower end, called the *pylorus*, in which is the *pyloric opening* leading to the small intestine. The form and dimensions of the stomach vary, of course, according as it is more or less full, or empty and collapsed. It may be made to hold three pints. The bulging part at the left end is called the *great cul-de-sac;* the part next to the pylorus is the pyloric end or *lesser cul-de-sac.*

The small intestine, extending from *d* to *i'*, is a smooth circular tube, of nearly equal diameter throughout, but becoming somewhat narrower as it descends. It measures about twenty feet in length in the adult, and is closely packed by being doubled about on itself, forming what are called its *convolutions* or windings. Certain portions of it receive different names. Thus the upper eight or ten inches, *d d*, are named the *Duodenum* (from δυοδεναι, *duodenai*, twelve, because its length is about equal to the breadth of twelve fingers); it describes a curve like a horse-shoe, its course being indicated in the figure by dotted lines, where it passes behind the large intestine. Two-fifths of the remainder of the small intestine, *j*, are called the *Jejunum* (from *jejunus*, fasting), because this part is usually found empty; and the lower three-fifths, *i i'*, constitute the *Ileum* (from the Greek ειλεω, to coil or turn).

The large intestine, in which the ileum terminates, extending from *c* to *r*, measures upwards of five feet, and becomes somewhat narrower as it proceeds. It is distinguished not only by its exceeding the small intestine in width, but also by its having a peculiar sacculated form, owing to the presence of three narrow bands running along it, which being shorter than the rest of the intestine, pucker up the intervening portions into three rows of *sacculi* or recesses. Its course is also very remarkable, for it nearly surrounds, as it were, the convolutions of the small intestine. It consists of the following parts: first, the *Cæcum*, *c*, or blind intestine (from *cæcus*, blind), because it ends in a pouch below; it has a singular little hollow appendage, *a*, called the *Vermiform* or worm-like *appendix*:—secondly, the *Colon* (from the Greek κωλον, which also signifies a division or member of a sentence in writing), *co* to *f*, divided into its *ascending*, *transverse*, and *descending* portions, *co*, *co*, *co*, and its *sigmoid* or *s*-shaped (σιγμα, the little *s*) *flexure*, *f*:—lastly, the terminal part or *Rectum*, *r* (from *rectus*, straight), which is straight in comparison with the rest of the intestinal canal; it does not possess the longitudinal bands and intermediate sacculi seen in the colon.

The Position of the Stomach and Intestines.

By referring to fig. 1, in diagram No. 3, and its description at p. 33, it will be seen that the convolutions of the small intestine, I I, occupy the middle and lower part of the abdomen, overlap the ascending and descending colon, and conceal the rectum, whilst the tranverse colon, K K, passes across the abdomen, just below the stomach, S, and a little above the situation of the navel or umbilicus.

Fig. 14 of the present diagram is a planned view of the deep-seated parts of the alimentary canal in the neck, thorax, and abdomen. The jejunum and ileum (excepting a very small piece of the lower end of the latter, marked *i*, which ends in the large intestine) are removed; and also a piece of the left lobe of the liver. The stomach, *s*, receiving the œsophagus, *o*, and the duodenum, *d*, are seen in their natural position. An uninterrupted view is also obtained of the cæcum, *c*, with its vermiform appendix, of the ascending, tranverse, and descending colon, *co*, *co*, *co*, with the sigmoid flexure, *f*, and of a part of the rectum, *r*. The liver, *l l'*, with its gall-bladder, *g*, partly overlaps the stomach, whilst the spleen, *m*, is attached to its great cul-de-sac.

It will be advisable, at this stage of the description, to reperuse the general account already given at p. 82, of the course which the food pursues and the changes which it undergoes in the abdominal portion of the alimentary canal. The mode in which the parts of the latter are adapted to their several uses will then be better understood.

The Attachments of the Stomach and Intestines.

The stomach, in which a certain quantity of food has to be accommodated from two to three hours, to be acted upon by the gastric juice, is firmly held to the diaphragm by the œsophagus at one end, and to the back of the abdomen by the duodenum at the other; its middle part is more free, so that it is tilted upwards and forwards, as its becomes filled, and falls back and down again as it is emptied. The duodenum, in which chylification begins, is much more fixed than the rest of the small intestine. If it were not so, the ducts of those large glands, the liver and pancreas, which, as shown in fig. 17, enter this part of the intestinal canal, might be inconveniently stretched or doubled up, and the passage along them be more or less obstructed. Great freedom of movement is permitted to the jejunum and ileum, which is highly favourable to the continual unfolding and narrowing of their convolutions, as the chyle is being absorbed from the alimentary mass moved along them. The cæcum is comparatively fixed; for here the digested matters nearly, if not quite, deprived of chyle, entering in successive portions from the small intestine, accumulate in considerable quantity and appear to undergo further changes,—indeed a sort of supplementary digestive and absorptive action. The ascending and descending colon are comparatively fixed, but the transverse part is more movable, so as to allow of its ascent or descent, according to the varying condition of the stomach as to distension. The sigmoid flexure, through which the residue of the food is conducted over the brim of the pelvis, is also rather movable, but the rectum again becomes more fixed.

The Peritonæal or Serous Coat of the Stomach and Intestines.

The several parts just mentioned are held in position within the abdomen by attachments of areolar tissue, blood-vessels, lymphatics, and nerves to the back of that cavity, and also in a special way by the thin, smooth, and transparent membrane, called the *Peritonæum*, already described with diagram No. 3, at p. 33, as lining the walls of the abdomen, and being reflected closely over most of the viscera contained in that cavity. It must not be supposed, however, that the cellular tissue, vessels, nerves, and peritonæum, which are all comparatively weak parts, have to bear in the upright position, the whole weight of the alimentary tube and its contents; for these are also supported, especially in that posture, by the broad muscles and tendons of the abdominal walls. The great pressure exercised by the muscles upon the contents of the abdomen is proved in vomiting, also by the production of hernia or rupture, which is a protrusion of the bowels through the abdominal walls, but under the integuments, caused by undue exertion; its effects are also seen in the instant and pertinacious escape of the intestines through a linear wound in the abdomen.

The peritonæum forms the outer or *serous coat* of certain parts of the abdominal portion of the alimentary canal, being smooth and moist on its free surface, and very distensible and elastic, so as to facilitate such changes of form and position as the several parts undergo.

The more fixed parts of the canal, such as the duodenum, the cæcum, and the ascending and descending colon, have only a partial serous coat, the peritonæum passing only over the front, or the front and sides of the tube,—the back part being held by areolar tissue.

In the more movable portions of the small intestine, the peritonæum incloses the bowel, except along a narrow line at the hinder or attached border, where it passes off in a *double layer*, which including the blood-vessels, lymphatics, and nerves, and reaching to the back of the abdomen, forms what is called the *mesentery*, in the manner shown in diagram No. 5, figs. 1 and 4, *m*, and described at p. 76. The mesentery, which thus serves to support or as it were suspend the small intestine, has a very peculiar arrangement, which must not be overlooked. The part which is attached to the vertebral column, is only a few inches in length, but the anterior edge connected with the intestine, is of necessity as long as that tube, that is, about twenty feet. Hence it is thrown into curled or folded forms like those of the curled varieties of parsley or cabbage; and thus, following or determining, as we choose to view it, the convolutions of the small intestine, permits it considerable freedom of movement and consequent variety of turn or bend.

In the case of the stomach, the most dilatable portion of the alimentary canal, the serous coat is not continuous around the entire organ, but the layers covering the front and hinder surfaces are derived from different parts of the peritonæum, and are only loosely connected together at the upper and lower borders of the stomach, where they pass off in double layers to other parts. Hence, this organ is placed between two layers of peritonæum, and in enlarging or diminishing, has a certain latitude of movement, independent of the elasticity of its peritonæal covering.

Besides the serous coat, which is partial, the abdominal portion of the alimentary canal has everywhere three other coats or *tunics;* viz. proceeding from without inwards, the *muscular coat*, the *cellular*, *areolar* or *submucous coat*, and the *mucous coat*, also called the internal *coat* or *lining membrane*. The simplest arrangement of these coats is in the small intestine, a short piece of which is shown in fig. 9, where the external, peritonæal or serous coat is marked *s*, the muscular coat, *m*, and the submucous and mucous coats together, *c*.

The Muscular Coat of the Stomach and Intestines, and the Movements impressed on the Food.

The muscular coat, thicker than the serous coat, consists throughout the whole canal of an external layer of *longitudinal fibres*, and of an internal layer disposed in a *circular* manner (see the figure). On the stomach, the external fibres, continuous with those of the œsophagus above and the duodenum below, are spread out, except along the upper and lower borders of the organ, where they are thicker; the internal circular fibres are thickest over the pyloric portion of the stomach, and at the pylorus itself a special ring of these projects inwards, so as to form the *pyloric valve*, fig. 15, *p*, which narrows, and during life can completely close that part of the canal, shutting off the stomach, *s*, from the duodenum, *d*. Lastly, there are a few oblique fibres, which spread out from the œsophageal end over the sides of the stomach. On the cæcum and colon the longitudinal muscular fibres are principally gathered into the three remarkable bands already described; whilst the internal circular fibres are scattered over the sides of the sacculi, and collected in the constricted parts between them. In the rectum the longitudinal fibres are once more spread out so as to form an even layer all round the tube; and are here, as well as the circular fibres, very numerous.

The muscular tunic of the stomach and intestines adheres closely to the peritonæal coat, but only loosely to the submucous coat next within. It consists of involuntary muscular fibres, diagram No. 9, fig. 37, and is the cause of all the gastric and intestinal movements.

During digestion, it undergoes a remarkable series of slow contractions of a vermicular or wave-like character, passing in regular succession along the tube, from its upper to its lower end, or from any given point downwards. By these movements, called *peristaltic*, the mucous membrane of the canal is kept accurately applied to the alimentary substances, which are also passed gradually onwards. They are involuntary movements, excited by the presence of the food and digestive juices, for they cease when the canal is empty: in ordinary circumstances they are unaccompanied by sensation, but they are readily influenced by certain emotions.

a. In the stomach the peristaltic actions subserve several important purposes. Thus, during digestion a few circular fibres close the œsophageal opening, occasionally dilating to allow more food to enter, or to permit the escape of gases which accumulate in the stomach, give rise to pain, and are accordingly expelled by the contraction of its walls. Slow and methodical contractions passing through the whole organ cause a very remarkable and continuous revolution of the alimentary mass from the great cul-de-sac, along the lower border of the stomach towards the pylorus, and back along the upper border to the great cul-de-sac again. Besides this, a partial circular contraction near the middle of the stomach appears sometimes to take place, which shuts off the cardiac from the pyloric portion, the former containing the more solid, and the latter the more pulpy or chymified part of the food, which by progressive waves of contraction is urged on through the pylorus into the duodenum. In this way, the masticated insalivated and digesting mass is exposed continually, by regular movements, to fresh points of the secreting gastric surface, is so clasped that it is always in contact with that membrane, and is so gently pressed and squeezed that its outer portions, as they are successively pulpified and converted into chyme, are as regularly and systematically rubbed off and conveyed to the pyloric opening. Here that singular circular valve, shown in fig. 15, *p*, with its strong muscular bands, refusing a passage to the larger unchymified portion, offers no resistance to the pulpy chyme, which is discharged in thick drops at a time into the duodenum. Regurgitation back into the stomach is prevented not only by gravitation down the fixed descending part of the duodenum, but also by the downward waves of the peristaltic movements of the duodenum. In disturbed conditions of the parts, bile and other matters may however flow up into the stomach. In the act of vomiting not only do the stomach and œsophagus contract, but the diaphragm and the abdominal muscles also co-operate involuntarily, under reflex nervous influence.

b. In the peristaltic movements of the small intestine, the longitudinal fibres shorten the canal, and unfold the convolutions one after another; whilst the circular fibres narrow it, and cause it to clasp the chyle-yielding mixture of chyme, bile, and pancreatic juice; thus favouring absorption by the lacteal vessels, and gently carrying the soft mass over fresh portions of the mucous surface, and finally propelling the residual and now more consistent portion from the lower end of the small intestine into the cæcum. At this point, fig. 5, between *i'* and *c*, there is a valvular contrivance to prevent reflux or regurgitation.

Fig. 16,—representing a section through the cæcum, *c*, and adjoining part of the colon, *co*,—shows this structure, which is called the *Ileo-cœcal valve*. The vermiform appendix is marked *a*, and the terminal piece of the ileum, *i*. The valve consists of two semilunar segments, between which is a nearly transverse slit-like aperture.

This double valve is formed by the intrusion of the flattened lower end of the ileum into the side of the cæcum and colon. The apposed surfaces of intestine adhere together, so that the segments of the valve consist of two layers of mucous membrane, one corresponding with that of the small intestine, and one with that of the large intestine, which are continuous with each other at the margins of the segments. They also contain the submucous coat, and some circular muscular fibres of each intestine; but the longitudinal fibres and the peritonæal coat pass directly from the ileum to the cæcum without entering into the formation of the valve. As the cæcum becomes filled and distended, the segments are stretched and their edges are pressed closely together. The action of the valve is very perfect, and is more mechanical than that of the pylorus, which depends for its closure entirely on the vital action of its muscular fibres.

C. In the large intestine, the peristaltic movements are very vigorous, and can contract the bowel to a very small size. By the co-operation of the three strong longitudinal bands with the universally disposed circular fibres, the now almost exuvial mass is, as it were, lifted from one range of sacculi to another, up the right side, across along the transverse colon, and so down the left side into the rectum.

The Cellular Coat of the Stomach and Intestines.

The cellular tunic of the alimentary canal is composed of a layer of loose and easily-distensible *areolar*, mixed with a little *yellow elastic* tissue, which follows all the variations of form in the different parts, as in the sac-like stomach, the contracted pylorus, the tube-like small intestine, the segments of the ileo-cæcal valve, and the ridges and sacculi of the colon. It adheres less firmly to the muscular coat without than to the mucous coat within, which latter it everywhere supports, and it is hence called *sub-mucous*. It also serves the important purpose of forming a matrix, in which the arteries divide and subdivide into sufficiently small vessels before they penetrate the minute complex and delicately organized structures belonging to the mucous membrane. It also receives from that membrane the small veins and lymphatics, which unite within it into larger branches before they pass off to the mesentery.

The Mucous Coat of the Stomach and Intestines, and their Secretions.

The internal or *mucous coat*, at which we finally arrive, forms the lining membrane of the whole canal. It differs widely from the mucous lining of the œsophagus and mouth,—with which, and through them with the skin, it is continuous,—in being somewhat thicker, but at the same time softer and more tender,—in being thrown in certain situations into distinct folds,—in having, instead of a squamous, a columnar epithelium (diagram No. 9, fig. 78),—in containing many more glandular structures, which are the seats of special secretions,—in having no sensitive papillæ,—in being covered, in the small intestine, with multitudes of minute projections called villi, and in being much more abundantly supplied with blood-vessels and absorbents.

a. When the stomach is empty the mucous membrane of that organ, together with the submucous coat supporting it, is thrown into numerous puckers or *rugæ*, which are spread out and disappear when the stomach is full. This is owing to the fact that the mucous and submucous coats, not being naturally so distensible, are of greater extent than the muscular and serous coats, and are only loosely connected with them. In this way, space is provided for a large mucous surface for secretion and absorption, and at the same time, any overstretching of the tender and complex mucous membrane, which might interfere with those functions, is admirably prevented.

The gastric mucous membrane has a pale dingy straw-colour, but this is modified during life by the varying quantity of blood in its numerous capillaries. Thus, during digestion it becomes of a brilliant red hue, as has been observed in the person of a Canadian, the interior of whose stomach is visible (for he is still living) through an opening in the side, resulting from a gun-shot injury. When digestion is over, the blood-vessels are comparatively empty and the membrane is pale. Its extended surface, apparently smooth to the naked eye, is seen, when examined with a watchmaker's lens, to be modelled into little shallow polygonal depressions called *alveoli*, the slightly-raised borders of which are sometimes fringed.

Fig. 6 shows the internal surface, and fig. 7 a section, perpendicular to that surface, of a piece of the coats of the human stomach, about $\frac{1}{40}$th inch square, magnified 260 diameters. At the bottom of the alveoli, fig. 6, are small circular spots, which are the mouths of little tubes, seen sideways at *a*, *b*, fig. 7,—*m*, representing the muscular coat.

These tubules, the *gastric glands* or *follicles*, are like little flasks, opening at one end into the interior of the stomach, but dilated and closed at the other end, *b*; they are found in every part of the stomach, densely packed, perpendicularly to the surface, and held together by an intermediate soft substance and the capillary blood-vessels. They are about $\frac{1}{400}$th inch in width, and are longer and even branched at their closed ends in the pyloric portion of the stomach, where the mucous membrane is thicker than at the cardiac end.

Fig. 8 is is a single tubule, magnified 650 diameters. It is seen to be composed of an outer basement membrane, *a*, lined in its upper half with a columnar epithelium like that of the gastric surface generally, but filled at its lower dilated end, *b*, with soft roundish or oval nucleated cells, called *glandular epithelium* cells, through the agency, and probably in the interior of which, the gastric juice is secreted or separated from the materials furnished by the blood. (See diagram No. 9,—Epithelium.)

During digestion, the fluid contents of the tubules charged with cells more or less broken down, ooze into the cavity of the stomach, the secretion being immediately excited by food or by any mechanical or chemical irritant. In the intervals between the meals, no fluid is poured out; and whether a fresh store of nucleated cells is then slowly prepared in the tubules, or whether these are suddenly developed during the active condition of the circulation whilst digestion is going on, these preordained intermissions in the digestive process are absolutely needed, and without such rest the stomach would speedily suffer. The gastric juice is secreted in very large quanties,—as much as 20 oz. in an hour, and therefore by several pints daily. It is a thin colourless acid fluid, containing, besides a few salts and free lactic, phosphoric, or hydrochloric acid, a peculiar and remarkable animal substance called *pepsin* (from *πεπτω*, to cook, or digest), which, acting like a ferment, causes the rapid solution in the acid fluid, at the temperature of the stomach, 100°, of all *protein* compounds, such as albumen, fibrin, casein, gluten, and gelatine. It is doubtful whether it wholly arrests the action of the saliva on starch, also whether it has any direct influence on that substance or on sugar: it seems incapable of acting on oils and fats. Besides the gastric tubules, a few rounded whitish follicles are seen scattered over the mucous membrane of the stomach, especially in infants and young children: their use is not known. Some conglomerate mucous glands exist about the œsophageal opening.

b. In the *small intestine*, the mucous membrane, naturally pale, acquires a more or less vivid red hue, according to the quantity of blood in its numerous capillaries.

When the intestine is contracted, the mucous coat, like that of the stomach, and for similar reasons, is thrown into irregular and temporary folds. But besides this, it is provided with numerous transverse crescentic *permanent* folds, which are not obliterated by distension of the intestine, but instead of that, project into the interior.

> Fig. 10, which is a piece of the jejunum laid open and represented somewhat enlarged, shows these permanent folds, named *Valvulæ conniventes*, arranged side by side across the bowel. They are placed at short intervals from one another, each extending about one-half or two-thirds around the intestine, and measuring about $\frac{1}{3}$rd of an inch across their widest part. They are found in the duodenum, within an inch of the pylorus, all through the jejunum, and in the upper half of the ileum, where, having gradually become smaller and less frequent, they finally disappear. Each fold or valve consists of two layers of the mucous membrane, united together by a supporting stratum of areolar tissue, prolonged from the submucous coat. They serve the important purpose of multiplying the absorbent surface of the small intestine.

It has already been stated, under diagram No. 5, p. 77, that one characteristic feature in the structure of the mucous membrane of the small intestine is the possession of little soft projections called *villi*, in which the lacteals commence; and that owing to the multitudes of these, its surface, when washed clean, and placed under water, no longer appears smooth or glazed, but has a velvety appearance, and is hence called a villous-mucous membrane. These villi exist on the valvulæ conniventes as well as between them: their total number is said to be upwards of four millions; they vary in length from $\frac{1}{40}$th to $\frac{1}{30}$th of an inch, being more numerous and of larger size in the duodenum and jejunum, but gradually becoming fewer and shorter towards the lower part of the ileum.

> Fig. 11 represents, magnified about 27 diameters, the little piece of intestine $\frac{9}{10}$ths of an inch in length, indicated as if cut out in fig. 10. It shows the villi springing up from all parts of the surface, like little flattish processes.

> In fig. 12, which is a perpendicular sectional view of a minute piece of the coats of the small intestine, magnified about 14 diameters, the villi, *v*, are shown, still further enlarged, standing up from the general surface.

Each villus is a true projection of the mucous membrane, consisting of a soft connective tissue, inclosing a lacteal vessel (diagram No. 5, fig. 5), supplied abundantly with capillary vessels (diagram No. 3, fig. 11, which is taken from the intestine of the hare) and covered, like the general surface of the mucous membrane, with a stratum of columnar epithelium,

—indicated in fig. 12 of the present diagram, and in diagram No. 5, fig. 5,—the separate particles of which are represented in diagram No. 9, fig. 78.

The milk-white chyle, which separates from the chyme after the admixture of the bile and pancreatic juice, passes into the lacteals of the villi either through the interstices, or else through the very substance of the epithelial nucleated cells, which at all events appear in some way to attract from the interior of the intestine, and then direct onwards into the lacteals that final product of the digestive process here destined to be absorbed.

In animals, and in man though less distinctly, pale contractile fibres are found in the substance of the villi, and may, by their contraction, favour the onward movement of the chyle in the central lacteal; some exist also in the mucous membrane generally.

The glandular structures in the mucous membrane of the small intestine are of three kinds; viz. a few true *conglomerate* glands, a vast number of *open tubular* follicles, and a series of *closed capsular* glands.

The *conglomerate* glands are little pea-shaped bodies, having branched ducts, found in groups in the upper part of the duodenum, and singly for some distance lower down. These are named Brunner's glands. They secrete an alkaline mucus, which lubricates the entrance into the small intestine, and protects it mechanically and also chemically against the acid chyme which here passes into it. Their secretion may likewise act on the food.

The *tubular* follicles are found everywhere throughout the small intestine, and, as shown in figs. 11 and 12, *f*, are placed perpendicularly to the surface, whilst their mouths appear like little dark spots, either scattered between the villi or forming little circlets around certain rounded or oval bodies, fig. 12, *g*, which are the capsular glands to be presently described. These tubules are named the intestinal *follicles* or the *crypts* of *Lieberkühn*, and remind one of the gastric follicles, but are shorter and more simple in structure, being lined throughout with a squamous epithelium (see fig. 12). The proper *intestinal juice* secreted by them is alkaline, and doubtless serves to protect the membrane. Besides this, however, it is said to possess a power of digesting or breaking down the proteinaceous compounds in food, imparting to them, however, a putrefactive tendency. It also changes starch into sugar.

The *closed capsular* glands of the small intestine exist either scattered singly throughout the whole length of the intestine, in which case they are called the *solitary* glands, or they are collected into rounded or oblong patches, which then receive the name of the *agminated* glands (from *agmen*, a group or cluster). These groups, also called *Peyer's patches* or *Peyer's glands*, are found at intervals upon the free border of the intestine, commencing by small clusters in the jejunum, and getting larger and larger towards the lower end of the ileum. There are about thirty patches in all. One is represented at *p* in fig. 10. In fig. 11, nine of the component capsules of the same patch are exhibited on a larger scale, surrounded by the dark orifices of the intestinal tubules, and having the villi placed between them. In fig. 12,—taken from the calf, and still further enlarged,—one of these closed sacs or capsules, with half of another, is seen cut through perpendicularly to the surface, completely embedded in the mucous membrane, and resting nearly on the muscular tunic marked *m*.

The use of these glands, whether solitary or agminated, is not clearly understood. Frequently they are so collapsed and empty as to be with difficulty distinguishable. During the absorption of the chyle, they become distended with certain milk-white contents, and are found to consist of a semifluid substance, consisting of nucleated cells and free nuclei. They have no duct opening on the surface of the mucous membrane, though they are occasionally found ruptured: they cannot therefore be classed as ordinary secreting glands. According to some, they are not so distinctly limited by a capsule as is represented in fig. 12; they are well supplied with blood vessels, which actually pass into their semifluid contents, and the lymphatics are very abundant beneath them. On the whole, it is conjectured that they have some special relation with the absorbent system, like the little closed sacs found in the tonsils and at the root of the tongue (see pp. 85, 90).

c. The mucous or lining membrane of the *large intestine* is paler and smoother than that of the small intestine: it has no valvulæ conniventes and no villi to increase its surface for absorption. That function indeed is much less active here; and the lymphatics accordingly are not so numerous, and only form a network spread out near the surface of the mucous membrane.

Scattered all over the membrane are many closed sacs or capsules, containing, when filled, a soft whitish granular substance, and resembling the *solitary glands* of the small intestine, except that they are placed at the bottom of a small pit or depression having a narrow mouth. Their use is probably of a similar kind, though this is not exactly known. They are very numerous in the little vermiform appendix. Surrounding them everywhere, and indeed closely studding the internal surface of the large intestine, so as to give it a cribriform appearance, are multitudes of tubular follicles or *crypts* of *Lieberkühn*, somewhat larger than those of the small intestine, but shorter than the tubules of the stomach. They secrete a protective fluid, which may also have some special use in digestion; but this is not determined.

Shortly to recapitulate the changes induced in the food as it passes along the alimentary canal, it may be stated that amylaceous or starchy substances are converted into sugar chiefly by the saliva, but, perhaps, also by the alkaline intestinal juice; that protein compounds are chiefly dissolved by the gastric juice, but secondarily also by some of the intestinal fluids; and that fatty substances are emulsified by the bile, and especially by the pancreatic secretion, which has been said to act also on starch and protein compounds.

In reference to the phenomena of absorption, which take place in the alimentary canal, it is certain that the chyle, first formed in the small intestine, is absorbed in the lacteal vessels; but it is also true that many soluble substances, such as sugar, alcohol, æthers, flavours, colouring matters, perhaps raw albumen and saponified fats, saline substances, many medicinal agents, and especially the great solvent water itself, are absorbed by the returning capillaries and the finest veins, both from the stomach and the small and large intestines. In this way, many nutritious substances doubtless find their way into the portal circulation, but are modified as they pass through the liver before they reach the heart. By this absorption through the vessels, also, an excess of water, which might hinder digestion, is got rid of,—a continual supply of fluid is kept up in the blood, to support the drain upon it, in the formation of so many ounces of saliva, gastric and intestinal juice, bile and pancreatic fluid,—and the residual indigestible mass is reduced in bulk and rendered better fitted for being grasped and urged on by the muscular walls of the lower portion of the alimentary canal.

The duration of the digestive process has been watched in the stomach of the Canadian already mentioned. It differs according to the kind and quantity of the food taken. Of meats, venison seems to be the most digestible, then turkey, feathered game, beef, mutton, chicken, veal, and, last of all, pork. Soups are not more quickly digested than meat, which, be it remembered, itself contains much water. Vegetable food is more slowly digested than animal, and it is an interesting fact that the alimentary canal is much longer in herbivorous than in carnivorous creatures.

For the relation of food to Nutrition and Animal Heat, see diagram No. 9; and for the rationale of Hunger and Thirst, diagram No. 7.

Figure 17.

The Liver with the Gall-Bladder, and the Pancreas.

The liver and the pancreas, the two important glands which pour their respective secretions, bile and pancreatic juice, into the duodenum, are sometimes named appendages of the alimentary canal.

The Liver.

The *liver* is a large, firm, reddish-brown organ, placed in the upper part of the abdominal cavity, in front of the aorta and vena cava, reaching from the back to the front of the abdomen, and occupying chiefly the right side, although it stretches across a little to the left side also. It is the largest gland, and, indeed, the heaviest organ in the body, weighing nearly 4 lbs. in the adult. Its size, shape, position, and connections will be understood by comparing the central figure of diagram No. 3, and figs. 13, 14, and 17 in the present diagram, in which it is marked either L, *l*, or *ll'*. Its upper smooth rounded surface fits accurately into the hollow vault of the diaphragm above, whilst its under-surface, unevenly concave, rests on the stomach and duodenum, the top of the ascending colon, the right kidney, and some other parts below. Behind and to the right side it is very thick, and is well protected by the vertebral column and the inferior ribs. In front it is much thinner, and is also covered by the ribs, but descends a little below them, for a small space, in the sitting or standing posture, as shown in diagram No. 3.

It may here be remarked, that whilst all the solid viscera of the abdomen, such as the liver, pancreas, spleen, kidneys, and supra-renal bodies, receive immediate support or protection from the skeleton, the hollow viscera, viz. the stomach and intestines, which are continually varying in size and position, correspond mainly with the soft part of the abdomen, and have to escape injury by yielding before external violence.

Like most of the abdominal viscera, the liver receives a peritonæal covering, but at certain situations this is wanting, the peritonæum being reflected from it on to adjacent parts, so as to help to fix the organ, and to support its vessels, ducts, and nerves. Of these peritonæal folds, which are variously strengthened by intermediate fibrous tissue, one, called the *broad ligament*, partly seen in diagram No. 3, fig. 1, and also in figs. 14 and 17 in this diagram, reaches from the liver, which it marks off into a right and a left lobe *l*, *l'*, to the diaphragm and front wall of the abdomen. In the free margin of this is the *round ligament*, fig. 17, *a*, a firm cord, resulting from an obliterated vein, which connects the liver with the umbilicus. At the sides, the liver is further held to the diaphragm by the two *lateral ligaments*, of which the left one is seen in fig. 14, just above the stomach. Lastly, behind and above, a very large surface of the liver is fixed directly to the diaphragm by cellular tissue, the peritonæum passing all round from one to the other, forming what is called the *coronary ligament.* Connected thus firmly with the diaphragm, the liver descends and ascends with that muscle during inspiration and expiration, as well as undergoes slight changes, according to the attitude of the body. It must not be supposed, however, that any dragging takes place, or that the action of the right lung is in any way assisted or impeded; for the liver is, of course, equally supported with the viscera below it by the musculo-tendinous walls of the abdomen.

The liver is encompassed with a proper *fibrous coat,* which not only closely invests every part of its surface, but, entering at a wide fissure on its under surface called the *porta, gateway,* or *portal fissure,* penetrates along numerous branching channels through the substance of the organ, and lines those channels or *portal canals,* as they are named, with a loose web of areolar and elastic tissue, called *Glisson's capsule,* which surrounds and supports certain blood-vessels and ducts, as well as lymphatics and nerves, lodged in the portal canals.

The compact mottled reddish-brown substance of the liver consists of an incalculable number of little closely-fitting polyedral masses, about the size of pins' heads, called *lobules* or *acini,* which are held together by the finest blood-vessels and ducts, and by a very delicate areolar tissue continuous with the fibrous tunic and Glisson's capsule. The outlines of these minute elementary parts or lobules may be seen on a section, and they give a granular character to a torn surface of the liver. Each is, in fact, a miniature gland, consisting of a proper gland *tissue* connected with the commencements of the *ducts,* and serving to secrete or separate the bile from the elements of the blood,—of larger ducts which convey the bile away,—and of two important sets of *blood-vessels,* with an intermediate *capillary network.*

A few words must be added on each of these subjects; viz. the blood-vessels, the secreting substance, and the ducts of the liver.

a. There is nothing more remarkable, because exceptional, in the body than the mixed source from which the liver obtains its blood; for, besides receiving a small quantity of arterial blood through a branch from the aorta named the *hepatic* artery (see p. 61), it is chiefly supplied through the *portal vein* (see p. 64) with venous blood already employed in circulating through the other abdominal digestive organs.

Fig. 13 is a plan of a median section of the trunk, to illustrate the circulation through the abdominal viscera, and show what is called the *portal circulation;* in other words, the mode of formation and subsequent distribution of the portal vein. The heart is marked *e.* The curved line below represents the cut edge of the diaphragm, separating the thorax from the abdomen. The aorta, *a, a,* gives off branches—here coloured pink—to the following parts;—the liver, *l,* the stomach, *s,* the spleen or milt, *m,* the pancreas or sweetbread, *b,* the small intestine, *i,* the great intestine, represented by the colon, *co,* and the rectum, *r;* and, lastly, to the right kidney, *k.* The names of these several arteries may be found by comparing this plan with diagram No. 4, figs. 1 and 7, and consulting the description of them at p. 61.

Of the veins of these parts, those of the rectum and the kidneys,—here coloured pale blue,—enter at once into the ascending vena cava *c*, and so reach the heart; but those from the stomach, spleen, pancreas, small intestine, and colon,—here coloured pale purple, —unite to form a great common trunk, *p*, which is the *vena portæ*, or *portal vein;* so called because it enters the porta or portal fissure of the liver, where it divides into a right and left branch, for its two lobes.

Within the liver, and running along the portal canals, the vena portæ divides and subdivides,—the larger subdivisions only being shown in the diagram,—until its branches, becoming very minute, penetrate the interspaces between the little lobules, and then entering their substance, end by forming the *capillary network*, from which the gland-substance obtains its materials for the formation of the bile. The portal blood therefore is the secreting blood of the liver.

The *hepatic artery*, which is so small in proportion to the great bulk of the liver, also enters and ramifies along the portal canals, and appears to be the nutrient artery of the liver, for its branches are distributed to the fibrous tunic, Glisson's capsule, and the coats of the larger blood-vessels and ducts. From these parts the blood is returned by small veins, which seem to empty themselves into the minute portal veins, before these latter terminate in the capillary network of the lobules. Hence the nutrient blood of the liver itself, just like that of the abdominal digestive organs generally, passes, after having become venous, into the current of its secreting blood.

From the capillary network of the lobules, the blood, having parted with much material and undergone remarkable changes, is poured by a little central vein, passing out at the base of each lobule, into the branches of a set of veins on which the lobules rest, called the *hepatic veins*, which uniting together into a few trunks,—shown in the diagram, at *h*, coloured pale blue,—escape at the back of the liver into the ascending vena cava, *c*, and so finally reach the heart. The hepatic veins occupy quite distinct channels in the substance of the liver from the portal canals, and have not any surrounding areolar web-like Glisson's capsule; for the lobules rest immediately upon their sides all round them.

Each lobule of the liver, then, possesses *afferent* portal veins on its surface, an *efferent* hepatic vein in its centre, and an *intermediate* capillary network.

b. The *secreting substance* of the liver, lying amidst the capillary network of the lobules, is of a pale yellowish colour, and consists of numerous microscopic nucleated cells, called the *hepatic cells* (shown in diagram No. 9, fig. 76), in the interior of which the bile is formed, and from which it escapes into the commencing ducts, either by transudation through the cell walls, or by the rupture of the same.

c. The *biliary ducts* commence, in some way, amongst the hepatic cells, probably by a close network of tubes, much wider than the capillaries and having the hepatic cells lining them like a glandular epithelium. From this network little branches pass off at the surface of the lobules, and join with others, so as to form larger trunks, which gain the portal canals, and then running in company with the branches of the portal vein and hepatic artery, but of course conveying their contents in an opposite direction, at length emerge in two trunks, one right and the other left, at the bottom of the portal fissure, where they unite finally into a single duct, called the *hepatic duct.*

Fig. 17 represents the liver, *l*, *l'*, with its round ligament, *a*, and the gall-bladder, *g;* also the stomach, *s*, its œsophageal end, marked *o*, and its pyloric extremity, *p*,

—all these parts being turned up so as to show the duodenum, *d*, the pancreas, *b*, and the spleen, *m*.

In this diagram, two biliary ducts are seen emerging from the liver, to form the single hepatic duct, which is itself speedily united to another proceeding from the gall-bladder, called the *cystic duct*. By the union of the hepatic and cystic ducts, is formed the *ductus communis choledochus*, or *common bile-duct*. This, as shown by the dotted line, passes down behind the duodenum, *d*, and coming into contact with the duct belonging to the pancreas, *b*, pierces obliquely, together with the last-named duct the walls of the duodenum, in the interior of which both ducts open usually by a common orifice at the summit of a small projection, situated about three inches below the pylorus (see fig. 15). At this point then, regurgitation being rendered impossible by the ducts passing obliquely through the muscular tunic of the intestine, the bile and pancreatic juice mingle with the successive portions of the chyme-pulp descending through the pyloric opening,—the result being the immediate formation upon the surface of the chyme of some of the white emulsion called chyle.

The *Gall-bladder*, marked in all the figures *g*, is a pear-shaped bag, capable of holding about two fluid ounces, and forming a diverticulum or reservoir connected with the biliary ducts. It is attached to the under surface of the liver (see fig. 17), by the cystic duct, by cellular tissue and vessels, and by the peritonæum, which covers its under part and sides, and then passes on to the liver. In its natural position, fig. 14, and diagram No. 3, fig. 1, the fore part or larger end of the gall-bladder is placed lower than the narrow part or neck connected with the cystic duct, projects at a slight notch in the anterior margin of the liver, and even touches the wall of the abdomen.

The gall-bladder has an external proper fibrous coat, in which plain or unstriped muscular fibre-cells are found, and an internal mucous coat, lined with a columnar epithelium.

Its internal surface is curiously marked by a multitude of fine ridges inclosing little polyedral recesses, in the bottom of many of which are the openings of mucous follicles. At the neck of the gall-bladder there are several constrictions, causing internal projections; and in the cystic duct the mucous membrane forms a series of crescentic folds, which almost resemble a spiral valve. All the larger biliary ducts have likewise a contractile fibrous and a mucous tunic,—the latter lined by a columnar epithelium and provided with ramified or else simple mucous glands.

The gall-bladder receives such bile as, not being immediately required for the purposes of digestion, is prevented from entering the duodenum, but flows along the cystic duct into this temporary reservoir. From it, changed only in being somewhat more inspissated and containing more mucus, it is again propelled, if required, by the elasticity and contractility of its fibrous coat, as well as by external pressure, on the part of the distended alimentary canal, along the cystic and common bile-ducts into the duodenum. The precise action of the spiral folds in the cystic duct is not well made out. The contractility of the gall-bladder and its ducts is governed by reflex nervous influence excited by the presence of chyme in the duodenum.

The *Bile* is secreted at the rate of about 50 oz. in 24 hours, corresponding with 2½ oz. of solid matter. It is a thin greenish-yellow fluid, in which are found some mucous corpuscles and epithelium cells. It is both sweetish and bitter, and has a neutral or faintly alkaline reaction. Its special constituents are two *fatty acids*, combined with soda, forming a soap, which doubtless assists in reducing the fat of food to a state of emulsion, at the same time that it helps to neutralize the acidity of the chyme. Besides this, the bile contains three colouring substances, a small quantity of cholesterine, some ordinary fats combined and uncombined with soda, and certain salts. Some at least of these constituents are probably reabsorbed from the intestine by the veins, and are consumed in the blood by its reoxygenation in the lungs; whilst others are more directly excretory products, which are speedily cast out of the system. In bilious people, and in what are called bilious attacks, the liver is often employed in getting rid of excessive quantities of certain ingredients, especially of fatty *hydro-carbonaceous* compounds from the blood.

There is no doubt also that the bile, more perhaps than any other ingredient in the contents of the alimentary canal, serves to stimulate the muscular coat of the intestine to a healthy peristaltic action.

Not only does the liver form and pour into the intestinal canal a fluid essential to the purposes of digestion, and intended also to remove injurious matters from the blood, but it has been lately shown that it has other somewhat associated offices of the highest consequence in the animal economy; for experiments have proved that the albumen in the portal blood, as it enters the liver charged with products absorbed from the digestive canal, is less perfectly formed and less fitted for use in the economy, than that found in the blood of the hepatic veins; and again it has been now pretty clearly established that a peculiar *glycogenic* or sugar-yielding substance, not present in the portal blood, but found in the hepatic blood, must be formed in the liver, either directly or indirectly through some other compound, out of the richly-loaded blood returning from the alimentary canal, the pancreas, and the spleen. This glycogenic substance swept along the inferior vena cava to the right side of the heart, disappears in the pulmonary circulation, where it serves as a respiratory fuel, and rids the venous blood perhaps of certain impurities,—thus at the same time performing an emunctory office to the whole body, and aiding in the production of the animal heat.

The Pancreas.

The *Pancreas* (from παν κρεας all flesh), fig. 17, *b*, commonly called in animals the *sweetbread*, is a cream-coloured tongue-shaped gland, placed deeply in the abdomen, across the front of the aorta and vena cava, and behind the stomach, lying with its large end or head in the curve of the duodenum, *d*, and its tip in contact with the spleen, *m*. It is held in position by areolar tissue, by its vessels and ducts, and by a partial and loose covering of the peritonæum.

The pancreas measures about seven inches in length and weighs about three ounces, more or less. It consists of many small portions called *lobes*, and these again of *lobules*, which have no common limiting membrane or coat, but are held together by the blood-vessels, ducts, and areolar tissue. Each lobule is a small racemouse gland, consisting of a branched duct ending in little dilated *vesicles* resembling in structure the salivary glands described at page 85, and represented in diagram No. 9, fig. 70. Collected by the small branched ducts from the various lobules and lobes, the fluid secreted by the pancreas is poured along the main duct, which is seen partly exposed as if by dissection, in fig. 17, and enters the duodenum with the common bile-duct in the manner already described.

From the sum of its characters, the pancreas has been called the abdominal salivary gland; but the pancreatic juice is by no means identical with saliva. It is a clear colourless fluid, containing a few corpuscles. Its reaction is naturally alkaline, and it contains many saline substances, but, unlike saliva, it has no sulphocyanide of potassium. It probably aids in the conversion of starch into sugar, but its peculiar property, dependent, it is believed, on the action of some organic ferment contained in it, seems to be that of converting the fatty matters of the food into an emulsion, so as, with the bile, to lead to the formation of chyle out of chyme. It is alleged to act also on protein compounds.

The importance of the liver and pancreas is shown by their widely-diffused presence in the animal kingdom. Both are found in all the vertebrate, and in the higher forms of invertebrate animals; whilst the liver exists in almost the very lowest forms of the latter, being perhaps the earliest gland to appear in the animal series. In reference, indeed, to the digestive organs generally, it may be said that the affinities between the vertebrata and invertebrata are more obvious and widely traceable than in the case of any other system of organs, whether locomotive, respiratory, circulatory, absorbent, or nervous; and this is what might be expected, if we consider the common animal necessity of taking food to live.

General Review of the Digestive Process.

From the lengthened description necessary to explain the parts exhibited in this diagram, some idea may be formed of the intricate anatomical arrangements of the digestive organs in man, and of the complex character of his digestive function.

The vital mechanics of the acts of prehension, mastication, and deglutition,—the latter involving a provision for the security of the respiratory passages,—the churning movement given to the food as it is gently compressed by the stomach,—the regulated guardianship of the pylorus,—the timely introduction of the bile and the pancreatic juice through carefully protected ducts and apertures,—the relative fixity or mobility of the different parts of the alimentary canal,—its lubrication throughout by a protective mucus, more abundant at particular points,—its curious creeping peristaltic action, insuring the onward movement of the food, and aiding the absorption of its nutrient portions,—besides and beyond all this, the vital chemistry of the digestive process,—the special actions of the mucus, the saliva, the gastric juice, the bile, the pancreatic fluid, and the intestinal juices, each yielding many ounces of fluid daily, and each contributing its share of fermenting or solvent power, —then the twofold method of absorption, by the blood-vessels and by the lacteals,—furthermore, the depurating influence of the liver and intestinal follicles,—the exceptional source of the blood supplied to that large gland, and finally—the remarkable change wrought in the constituents of the blood as it circulates through the hepatic substance, by which a fuel is provided for respiratory combustion,—present a combination of wonderful contrivances and actions, not more perfect, but surpassing in complexity of detail, the comparatively simple structure and functions of the respiratory and circulatory organs.

But the purpose to be fulfilled in the digestive process is itself far more complicated. Heterogenous articles of diet, vegetable or animal, raw or cooked, with structures more or less difficult to break down, themselves the products of vital action, dead though not decomposed, have to be so prepared and elaborated as to yield up materials again fitted to enter into the tissues and reassume a place and office in the organs and affinities of a living creature. For it will be observed that all the remarkable agencies to which the food is submitted up to the moment of venous or lacteal absorption, exert their influence upon it really *outside the living tissues;* and, though contained within the body, the elementary substances undergoing mechanical and chemical preparation, are merely in contact with the surface of the living mucous membrane, and do not, until their appointed time, and in their appointed condition, pass its epithelial frontier.

It is true that animals, unlike vegetables, which live on inorganic matter, require as food substances already formed by organic action; and such substances necessarily, in the case of animal food and actually in the case of vegetable food, possess a chemical composition similar to that of the constituents of the living animal tissues and blood. Nevertheless they require—and we cannot wonder at it—to go through the varied evolutions of a complex digestive process, before those recondite changes, perhaps of molecular condition rather than of mere chemical composition, can be brought within them, which give them an aptitude for vital affinities, bring them within the grasp of vital attractions, and enable them again to participate in the manifestation of vital acts.

Neither can it be matter of surprise that the digestive organs are so frequently, at both extremes of civilized society, the paths of entrance of serious and fatal disease.

The quantity of the food, both solid and liquid, its nature, quality, and condition as to preservation, are of prime importance in the digestive process. If the diet be defective or in excess, ill-selected, over-rich, too stimulating or decomposed, the nutriment actually thrown into the blood must deviate from a healthy condition. Defective mastication and insalivation from too hasty swallowing of the food, and defective chymification, chylification and absorption, from undue exertion of the muscular system or brain soon after meals, or from too great frequency of taking food, or from taking too much at a time, must also interfere with good digestion. Indigestion and all its consequences ensue. The digestive organs are themselves the first to suffer. The *primary assimilation* of nutriment into the blood is improperly performed, and that fluid becomes tainted or lowered in quality; then the *secondary assimilation* of nutritious matter by the tissues from the blood becomes affected, and so, not only the other parts of the system, but the digestive organs themselves, are weakened, their secreting and absorbing powers are impaired, and so a vicious circle of evil is established. Efforts may be made by the excreting organs to counteract the mischief, but always to their own cost; and the frail organism at some part or other at last gives way.

Legions of individual and social miseries are brought upon mankind by the abuse of lawful articles of food and drink. In a social point of view, the abuse of alcohol is a greater vice than an excess in solid food; but to the individual the evils resulting from the latter, though less sudden in their onset, and less obvious in their progress, are almost as serious in their results.

In the habitual drunkard, the coats of the stomach lose their tone and their power of secreting healthy gastric juice; the capsule of Glisson surrounding the portal veins, and the hepatic arteries and ducts within the portal canals of the liver, becomes the seat of a morbid deposit,—even in those who indulge largely in ardent spirits, though not actually drunkards. By its subsequent contraction, this deposit draws up the liver in all directions, strangles in its deadly clasp the blood-vessels and ducts, causes alterations in the substance of the gland, and thus lays the foundation for dropsy and for other diseases, which end only with the extinction of life. In other cases, and much more speedily, the brain and spinal cord become affected by alcoholism, the natural consequences of which are exhaustion of nervous power, tremors, depression only to be relieved by a renewed debauch, and want of self-control to resist temptation; and at last, one of many seizures of delirium tremens, or the delirium of drunkards, brings to a close a useless and wretched existence.

It is the duty of the public moralist and social philosopher to follow this subject in its effects on civil and domestic life; but we cannot refrain from expressing our reprobation of those who are slaves to the mere gluttony of a wasteful board, when we reflect on the numberless examples daily to be found at our hospitals and dispensaries, in which the slow starvation of a daily defective diet has evoked disease or is retarding the eagerly looked-for cure. Obesity, gout, and fatty degenerations of the organs on the one hand, wasting, scrofula, and rickets on the other, may balance the award of physical punishment; but the moral delinquency is surely greater in the wilful than in the necessitous offender against the laws of organization common to both.

The Spleen.

The *Spleen*, figs. 14 and 17, *m*, also diagram No. 3, fig. 1, M, or, as it is named in animals, the *Milt*, is a soft bluish-purple, highly-distensible organ, found in contact with the cardiac end of the stomach. From this circumstance, and also because of the connection of its veins with the portal system, it may be conveniently described with the digestive organs. Having no ducts, the spleen is not like a secreting or excreting gland; but from the organic action which it undoubtedly must exert on the blood which passes through it, it is called, like the thyroid body and supra-renal capsules, a *blood-gland*.

The spleen is attached to the stomach by numerous blood-vessels, and is also fixed to that viscus and to the diaphragm by suspensory folds of peritonæum. It accordingly shifts its position with both of those parts. It also lies near the tip of the pancreas, as shown in fig. 17, where the stomach is turned up, and the vessels and peritonæal connections of the spleen are removed. The greater part of the surface of the spleen, covered closely by peritonæum, is free; an arrangement which facilitates its remarkable variations in size, which are of greater extent than those of any other organ in the body. Though ordinarily covered by the left ribs, it descends below them when fully distended, as seen in diagram No. 3.

When moderately distended, the spleen is about 5 inches in length. It is rounded and smooth on one surface, to fit the diaphragm; but on the side next to the stomach is hollowed, and marked by a vertical fissure called the *hilus*, at which the blood-vessels pass in and out.

The spleen is composed of a fibro-elastic framework, of a proper substance, and of blood-vessels, lymphatics, and nerves.

The framework consists of a strong and highly elastic coat made up of areolar and elastic tissue, and in animals, at least, containing pale contractile fibres. From its internal surface multitudes of little bands, called trabeculæ (from *trabs*, a beam), closely intersect the spleen in all directions, being attached to certain elastic sheaths formed around the blood-vessels by the prolongation of the outer elastic coat upon them as they enter at the hilus.

In the meshes of this elastic reticular framework are the arteries and veins, the former split up into very fine vessels, the latter forming a close plexus of largish vessels, and here and there special dilatations. The proper substance of the spleen also occupies the spaces between the trabiculæ, lying outside the veins, whilst the arteries ramify amongst it. It is so soft, that it may be squeezed or washed out of the elastic framework or vascular tissue, and is then called the *splenic pulp*. It is of a dark reddish colour, changing quickly to bright red on exposure to the air. It consists microscopically of granular bodies, round and caudate nucleated cells, free nuclei, and large cells containing blood-corpuscles in different stages or conditions, retrograde or developing, it is not quite positive which. There also exist in the spleen, attached to the minute arteries, little whitish bodies, averaging $\frac{1}{40}$th of an inch in diameter, called *Malpighian corpuscles* of the spleen, consisting of microscopic elements, similar to those of the red pulp, but pale and colourless.

The splenic artery, the largest of the three branches of the celiac axis (diagram No. 4, figs. 1 and 7, also fig. 13 of this diagram), is of such calibre, that a very great quantity of blood may be sent to the spleen in a given time in proportion to the size of the organ. The *splenic* vein, which returns some of the blood from the stomach and pancreas, is also very large, and ends in the portal vein.

It is chiefly by an increase in the amount of its contained blood, that the dimensions of the spleen are occasionally so singularly enlarged, and in consequence of the expulsion of this blood, by the contraction of its elastic framework, that it again becomes reduced in size. It is usually most distended about four or five hours after a meal; and hence it has been thought that, when the portal circulation is necessarily loaded by the venous absorption going on from the alimentary canal, the spleen, through its vein, which, like the rest of the portal system, has no valves, acts as a diverticulum for the blood. So, too, it has been supposed that, when the circulation through the liver is impeded from congestion or from obstruction at the heart, the same mechanical office may be performed; and in the cold stage of intermittent fever or ague, where the general circulation is embarrassed, the spleen actually becomes enlarged. It is not known, however, whether such diverticular action is purely mechanical, or whether it is not partly, at least, the result of some harmonious action between distant parts associated by nervous influence.

The part which the spleen plays in regard to the blood which flows through it is variously explained,—either as if it fitted that fluid for the secretion of the bile, or acted somewhat after the manner of the lymphatic glands in effecting the more perfect elaboration of the blood, or was concerned specially in the development and production of the red corpuscles, or, lastly, was the organ in which these latter are arrested, disentegrated, and destroyed.

It is certain that disease of the spleen is associated with a remarkable diminution in the red corpuscles of the blood, and an increase, perhaps chiefly relative, in the white ones. Such a condition may, however, occur where the lymphatic glands only are affected.

When to this account it is added, that the spleen may be extirpated from living animals without causing their death, or even any permanent injurious effect,—its essential functions, whatever they may be, being then taken up by other parts of the economy, probably by the lymphatic glands,—the uncertainty of our knowledge concerning the operations of this singular organ will be very apparent. It affords indeed an excellent example of the difficulties attendant upon the solution of an abstruse physiological problem.

No. 7.—The Brain and Nerves.—The Organ of Voice.

◆

THIS diagram is devoted chiefly to the illustration of the *Nervous System;* but it also contains five views of the *Larynx*, or *Organ of Voice.*

Fig. 1 represents, as seen from above, the brain of a fish, a batrachian, a bird, and one of the lower mammalia. A, B, C, D, shows them of their natural size, and A, B, C, D, enlarged two and a half diameters.

Fig. 2, E, F, G, shows similar views, on a natural scale, of the brains of three mammalia of higher organization.

Fig. 3 shows the upper surface of the *Human Brain*, of the natural size.

The preceding figures, placed in series, give a comparative view of the size and form of the brain in different vertebrate creatures, from the Fish up to Man.

Fig. 4 is an under view of the human brain, with a front view of the prolongation from it, called the *Spinal Cord.* It also shows the attachments of the nerves to both those parts.

Fig. 5 represents the brain and spinal cord lodged in their natural position within the skull and the vertebral canal, which are here cut through along the middle line of the body.

Fig. 6 is an horizontal section through the brain.

Fig. 7 is a vertical section through the brain and the upper part or commencement of the spinal cord.

Fig. 8, enlarged about five diameters, represents two transverse or horizontal sections, one, A, through the spinal cord, and the other, B, through the cord and certain membranes which surround and support it.

Fig. 9, in the centre, exhibits the position and course of some of the nerves which proceed from the brain and spinal cord to various parts of the body. It also displays the *Sympathetic Nerves*, which are chiefly distributed on the blood-vessels of the viscera.

In this figure, the nerves are in all cases represented as white branching cords. The colours employed to distinguish other parts are in harmony with those used in other diagrams.

Certain *superficial* nerves, lying immediately beneath the skin, are shown in the face and upon the right limbs; whilst *deep-seated* nerves are exhibited in the neck, chest, and abdomen, and upon the left limbs.

To display the superficial nerves, the integuments only are supposed to be removed, so that on the head and face the nerves are seen crossing over the superficial muscles; whilst in the right arm and leg they rest, together with the superficial veins, upon the fascia of the limbs. These superficial nerves are, however, but offsets of deep-seated nervous trunks, which perforate the fascia at certain points.

In the left limbs, some of the muscles are cut across near their attachments and removed; by which means, the principal artery and veins, accompanied here and there by the deep nerves, are displayed. In all cases, the chief branches only can be shown.

In the neck are seen the pharynx, and in front of this, the larynx, or organ of voice, with the thyroid body placed just below it. The neck being opened down into the chest, the pharynx may be traced into the œsophagus, and the larynx into the trachea. Within the thorax the heart is seen, and the aorta,—the other great vessels being cut short.

Just below the heart, a portion of the diaphragm, *d*, is left, attached to the vertebral column behind, and to the ribs in front. Below the diaphragm, within the opened cavity of the abdomen, are seen a part of the stomach connected with the œsophagus, also a part of the small intestine with its mesentery, and the right kidney. A piece of the abdominal aorta, and the branches for the stomach, intestines, and kidney, are likewise shown.

Nerves may be traced to all these parts, in the neck, thorax, and abdomen.

Moreover, along the right side of the vertebral column, so far as that is exposed, is seen a knotted cord, which is the right trunk of the so-called *Sympathetic nerve, sy, sy*, the branches from which proceed to the several viscera. The knotted portions of this nerve are coloured pinkish-grey, whilst the intermediate cords are white.

Lastly, this figure exhibits, on the right side, the way in which the nerves arising from the spinal cord, in the manner represented in fig. 3, pass out sideways between adjoining vertebræ to reach their destination.

Fig. 10 is a magnified representation of the ultimate ramifications of the nerve-filaments upon the muscular fibres, these latter being coloured pink, whilst the nerve-filaments are left white.

Figs. 11 to 15, relating to the structure of the organ of voice, will be described in order after the nervous system.

THE NERVOUS SYSTEM.

The *Nervous System* is the proper recipient of all sensory impressions: by regulating the muscular contractility it governs all animal movements, whether these be voluntary or involuntary; and, speaking of course in a material sense only, a certain part of it, viz. the brain, is the seat not only of consciousness to external impressions or sensations, but of internal sensations, emotions, or passions, and the organ of memory, ideas, reason, and will. Lastly, the sympathetic portion of the nervous system exercises, through the vessels, some controlling influence on the organic functions, such as digestion, circulation, nutrition, secretion, and respiration.

There are many minute creatures, belonging to the lowest forms of animal life, in which no nervous system has yet been detected; and in regard to certain of the very lowest, as in the infusorial animalcules, one can scarcely conceive that any such apparatus exists; in which case, however, these creatures must be regarded as destitute of sensibility and self-control, and as moving about and seizing their food in consequence of the direct stimulation of their muscular tissues, by such agents as light, heat, oxygen, water, or alimentary substances.

In its earliest recognizable form in the invertebrate animals, the nervous system is composed of two kinds of parts, viz. of little knotted masses of a pale-*grey* colour, called *Ganglia*, and of slender *white* cords, called *Nerves*, which nerve-cords either pass from one ganglion to another, or proceed from them to various parts of the body.

The ganglia appear to be the seats of the special powers of these simple forms of the nervous system; in them sensation takes place, and in them originates the force which excites or regulates muscular movements. The white cords serve to connect the ganglia where there are more than one, to conduct sensory impressions to them from different parts of the body, and to convey a controlling motor influence, in most if not in all cases, automatic and not voluntary, from the ganglia to the various contractile tissues.

In such invertebrata as possess a nervous system, the ganglia differ in number, size, position, and connection with each other, according to the varieties of form, structure, and office of the component parts of their bodies. One set of ganglia always regulates the organic functions, such as digestion, circulation, and respiration; another set presides over the locomotive apparatus; whilst a third set, not present in the lowest forms, belonging to the sensory organs, and serving probably in the highest forms as centres for producing combinations of action to certain ends and purposes, may be said to typify, though in a very feeble manner, the brain of the vertebrata. In even the highest of the invertebrata, however, the nervous system is but a small proportion of the whole animal, and the protection it receives from the surrounding tissues is very slight. Moreover, a certain number of the ganglia and their connecting cords usually surround the anterior extremity of the alimentary canal; whilst, in the general plan of the invertebrate series of animals, especially well exemplified in worms, insects, spiders, lobsters, and crabs, the great extensions of the nervous system into the body of the animal are placed in the middle line along the under side or *abdomen*, —the circulatory apparatus being along the dorsum or back, and the alimentary canal between the two.

In the vertebrate series, the nervous system also consists of masses of *grey* nervous matter, which are the *centres of action*, and of *white* nerve-substance, which serves a *conducting office;* but, *as a system*, it now assumes a far higher development. No part of it specially surrounds the entrance to the alimentary canal; its most important masses or centres are arranged longitudinally in the middle line, along the *dorsal* aspect or back,—the heart and great blood-vessels being next beneath it, and the alimentary canal on the under or abdominal side. Moreover, these great nervous centres are amply protected within the central bony axis of the skeleton, so fundamentally characteristic of the vertebrate organization.

There is still one part, namely the *Sympathetic nervous system*, which is composed, as shown in the human body, fig. 9, *sy'* to *sy*, of ganglia connected by intermediate whitish cords, the branches of which system are distributed along the arteries to the viscera and other parts of the body. But by far the larger portion of the grey matter of the vertebrate nervous system is collected into masses, or developed into layers, which, variously combined with very large quantities of white substance, from the great central nervous axis, consisting of the part called the *Brain*, situated in the cranium, and the part named the *Spinal Cord*, inclosed in the vertebral canal. The cranial part, also termed the *Encephalon*, —from εν, and κεφαλη, the head;—generally called the brain, is subdivided into the *Medulla Oblongata*, shown in Man, in figs. 4, 5, *m*, which is merely the continuation of the spinal cord, *c*, up into the head,—the *Cerebellum* or *little brain*, *b*, and the *Cerebrum* or *brain proper*, *a*. These several nervous masses together constitute the *cerebro-spinal axis*, from which are given off in symmetrical pairs, right and left, certain white cords, called, according as they escape from the cranium or vertebral canal, the *cranial* and *spinal nerves*. These nerves, which, together with the brain and spinal cord, constitute the *Cerebro-spinal nervous system*, branch out to all parts of the body, and besides, establish frequent intercommunications with the sympathetic system already mentioned.

Each of those systems must now be separately described, and their functions explained.

The Sympathetic Nervous System.

Besides the two knotted or gangliated cords placed one on each side of the vertebral column from the neck down to the coccyx, as shown in fig. 9, *sy* to *sy*, the sympathetic nervous system, or *ganglionic system* as it is sometimes called, includes many other ganglia situated at a distance from these, but intimately connected with them by intermediate nervous cords. Some of these are found in the face, others are situated in the neighbourhood of the heart; one very large ganglion, by some regarded indeed as the great centre of the sympathetic system, is placed in the abdomen, fig. 9, *g*; and lastly, another is found behind the pelvic viscera.

From all these ganglia, whether situated near the vertebral column or elsewhere, and also from most of the connecting nerve-cords between them, numerous branches, called *sympathetic nerves*, are distributed to all the organs and viscera of the body, and also, though in smaller proportion, to the head, trunk, and limbs. These chiefly find their way upon the arteries, and are very abundant upon the visceral arteries, around which they form plexiform meshes mixed with masses of grey matter or minute ganglia.

The fact, already alluded to must not be overlooked, that the sympathetic nervous system, just described, is connected by frequent intercommunicating branches with the cerebro-spinal system,—in the face, with certain of the cranial nerves,—in the neck and thorax with others of the cranial nerves which descend to those parts,—and along the entire vertebral column, as shown in fig. 9, with branches of all the spinal nerves in succession. It may be added also, that certain ganglia, which, as hereafter explained, are situated upon most of the cranial and spinal nerves near their origin, are believed by many to belong really to the sympathetic system.

The *cranial* portion of the sympathetic system consists of grey-looking branches, called from their softness *nervi molles*, which surround and accompany the internal carotid arteries into the skull, following the branches of those vessels into the brain, and establishing at various points communications with the facial part of the sympathetic.

In the *face*, the ganglia, though small and numerous, are constant and symmetrical on the two sides. One in the orbit, associated with the nerves going to the eyeball, is called the *ophthalmic ganglion;* two others, called the *spheno-palatine* and *naso-palatine,* are connected with nerves belonging to the nose and palate. A fourth, called the *otic,* is associated with the nerves of the deep-seated structures of the ear; and lastly there is a *submaxillary ganglion* connected with the nerves of the tongue and salivary glands;—so that this the facial part of the sympathetic system distributes branches to the organs of the special senses.

In the *neck* the ganglia are three, or sometimes only two in number,—as seen in fig. 9, *sy'*. The *superior cervical ganglion,* by far the largest of the entire sympathetic chain, gives off the nervi molles which ascend into the cranium on the internal carotid artery, and supplies others which pass forwards to the pharynx, tongue, and thyroid body. The *middle cervical ganglion,* where it exists, sends offsets to the thyroid body and the larynx. The *lower cervical ganglion* sends branches into the thorax, to the plexus which supplies sympathetic nerves to the heart and lungs. The heart also receives sympathetic filaments from the superior and middle cervical ganglia.

Of the dorsal ganglia lying in the thorax, as seen in fig. 9, *sy'*, *sy*, twelve in number, the upper five supply branches which reach the œsophagus, trachea, bronchi, and aorta, whilst the lower seven are chiefly devoted to the formation of two large visceral nerves called *splanchnic nerves,* from *σπλαγχνον,* a viscus, which pierce the diaphragm and join the sympathetic system in the abdomen.

The principal plexus in the abdomen, called the *great solar plexus,* fig. 9, *g,* is chiefly formed by the union of two large ganglia, named the *semilunar ganglia,* in which the splanchnic nerves terminate. It is placed in front of the aorta, around the short arterial trunk, known as the cœliac axis, which gives off the coronary artery of the stomach, and the hepatic and splenic arteries. Upon these arteries, and also upon the artery of the mesentery, *e,* numberless branches pass off like *rays* (hence the name *solar,* from *sol,* the sun), to the liver, pancreas, spleen, stomach, and intestines. Besides this, there are the *renal plexuses, k,* situated on the renal arteries, which derived partly from the solar plexus and partly from the lowermost splanchnic nerves, supply branches to the kidneys.

The *lumbar ganglia,* five in number, *sy,* and the *sacral,* four or five, give off branches which reach the aorta, and form plexuses on the pelvic arteries for the pelvic viscera. The sympathetic nerves of the heart and small intestines, and perhaps of other involuntary muscular organs have minute ganglia placed on the viscera themselves, which might be called *intrinsic* ganglia.

The sympathetic nerves found upon the arteries of the limbs and trunk, are derived from the adjacent parts of the two great ganglionated cores.

The microscopic structure of the ganglia and cords of the sympathetic nerve will be further described under diagram No. 9; but here it is necessary to state generally, that the grey matter of the ganglia consists of vesicular nucleated cells, called *nerve-cells,* diagram No. 9, fig. 44, mixed with a number of peculiar *grey nerve-fibres* called *gelatinous nerve-fibres,* diagram No. 9, fig. 43. The connecting cords and the branches of the sympathetic nerve are composed chiefly of these same fibres. Besides this, however, the ganglia, the intermediate cords, and the branches, all contain a few *white nerve-fibres,* called *tubular nerve-fibres,* identical in appearance with those which, as will presently be mentioned, compose the white substance and nerves of the cerebro-spinal system, diagram No. 9, fig. 39.

Some of these tubular fibres are undoubtedly derived from the cerebro-spinal system, coming to the sympathetic nerve along the frequent intercommunications between them; but others may be proper to the sympathetic itself,—originating in the grey substance of the ganglia. Just as the cerebro-spinal system imparts a few white fibres to the sympathetic, so at the several points of communication between them, grey or gelatinous fibres pass from the sympathetic to the cerebro-spinal nerves, and thence reach even the brain and spinal cord.

From the universal distribution of the sympathetic system, the anatomy of which is well known, its functions, though not quite understood, must be of great importance.

The ganglionic grey substance is to be regarded as the seat of its peculiar powers, but in all reflections on this subject, it is important to remember the interchange of nerve-fibres between it and the cerebro-spinal system; for it is evident that the sympathetic cords which contain white fibres, derived from the brain or spinal cord,—and nearly all of them do,—are to that extent cerebral or spinal nerves, and must bring the organs to which they are distributed more or less under the influence of the grey matter of the cerebro-spinal system.

Such organs, indeed, as the lungs, the heart, the intestines, and other viscera, are endowed with but a feeble sensibility, that is to say, the ordinary impressions produced by touch or contact, for example, are but imperfectly conveyed from them to the sensorial centre or brain. This feeble sensibility, wisely provided to relieve the attention from a useless and distracting cognizance of the action of these internal organs, is capable of being more or less exalted, and then may give important warnings, as of the necessity for food or air, or of the onset of inflammation, or of the presence of noxious substances in the alimentary canal, or of other threatened mischief. So too, the movements of all such parts, as of the heart and the intestinal canal, though quite involuntary, may be influenced in some way or other, as by fear or other emotions, the effect of which can reach them only through the cerebro-spinal nervous system. It has been concluded, therefore, that some of the white fibres in the sympathetic nerves are sensory fibres, which are connected with the brain, and convey to it through the spinal cord sensorial impressions, the feebleness of which, under ordinary circumstances, in in accordance with the small number of cerebro-spinal nerve-fibres which reach these, in comparison with more sensitive parts. Others of the white fibres again, it is concluded, are motor fibres, connected with the brain or cord, and subjecting the contractile tissues of the organs to which they are distributed, to peculiar influences originating in those great nervous centres, as will hereafter be fully explained.

As to the proper fibres of the sympathetic nerves, whether tubular or gelatinous, which commence in the various ganglia, including the intrinsic ganglia of the hollow viscera, they must play the part of afferent or efferent fibres, conveying impressions to and from the several ganglia, without our consciousness, and independent of our will. In this way important actions, such as the movements of the heart, intestines, gall-bladder, and the ducts of glands, dependent on unknown rhythmic influences, or excited by the presence of natural stimuli, appear to be quietly regulated without attracting the least notice or demanding any of our care.

Finally, it is believed that the sympathetic nerve controls in some way the silent and indeed unrecognizable molecular movements incident to nutrition and to the analogous process of secretion; and considering the large proportion of gelatinous fibres contained in the sympathetic nerve, and the fact that it is these which principally compose the soft nerves spreading themselves everywhere upon the coats of even the smallest arteries, it is conjectured that any such governing power possessed by the sympathetic may be exercised in part, if not wholly, through the action of those fibres upon the contractility of the arteries, —thus regulating the quantity of blood which may reach the parts which they supply. It has been shown, indeed, that when, in a rabbit, the sympathetic nerve is cut across in the neck, the blood-vessels of the ear become dilated and congested,—a condition which is immediately relieved by stimulating with galvanism the upper end of the divided nerve.

From their influence on the nutritive processes, and from supplying the viscera so largely, the sympathetic nerves are called the *nerves of organic life*, and their gelatinous fibres, *organic nerve-fibres*, to distinguish them from the cerebro-spinal system, or nerves of *animal life*.

The term *sympathetic* expresses both less and more than the truth; for these nerves are not devoted exclusively, as was once supposed, to the conveyance of sympathies; nor are they the channels of all the sympathies in the body.

The Cerebro-Spinal System.

Under this designation are included the Brain and Spinal cord, and the Cranial and Spinal nerves.

The Brain and Spinal Cord.

There is no part of the nervous system which manifests such striking differences of conformation in the different classes of vertebrate animals as that contained within the cranium, and generally known as the brain; and the very obvious fact that the mental endowments of these several classes progressively keep pace with the structural complexity of their brains, affords us the most direct proof that all such capacities, from the feeble sense of a fish to the highest of our own intellectual qualifications, are exercised through the intervention of this remarkable organ, suitably varied in size, in form, and in internal arrangement, to meet the requirements of every degree of psychical endowment.

> In figs. 1, 2, and 3, are represented the brains of the codfish, fig. 1, Aa, the frog Bb, the pigeon Cc, the rabbit Dd, the cat, fig. 2, E, the sheep F, the monkey G, and lastly, of man, fig. 3.

On comparing that series of figures in which the natural dimensions are preserved, it will be seen that the Human Brain is absolutely much larger than any of the others; and this is true even in regard to the brains of the largest animals, excepting only the great whales and elephants, whose brains are necessarily large, owing to the size of the nerves given off from them to supply their vast muscular system and their sensory organs. In proportion to the size of the nerves which spring from it, the human brain, however, is larger than any other.

The relative superiority in size of the brain of man is also shown by its weight being heavier, in proportion to the whole body, than it is in animals generally, although there are exceptions amongst the warm-blooded creatures, such as the smallest monkeys and little birds. As a rule, however, it has been computed that the relative weight of the brain to the body in the class of Fishes is about 1 to 5,600, in reptiles 1 to 1,300, in birds 1 to 200, and in mammalia 1 to 180; whilst in Man, it is 1 to 36. The proportion is the same both in males and females, though the male human brain weighs, on an average, 50 oz., whilst in the female, in accordance with her smaller size, its average weight is about 44 oz.

In studying the following account of the forms of different brains, reference is to be made to the enlarged representations of those of the fish, frog, pigeon, and rabbit; and the short lines placed to the left of the figures marked A to G, are intended to assist the reader in finding out corresponding parts in the different brains. These lines are placed on a level with the hinder part of the cerebrum, except by accident in the case of the fish, where the line is too far back.

In the Codfish, A, the brain consists essentially of three pairs of symmetrical masses of nervous substance. First, in front of all, are two elongated masses named the *Olfactory Lobes*, because they have connected with them the nerves of smell, or olfactory nerves. Behind them are two rather larger but still very small masses, which chiefly represent certain deep-seated portions of the cerebrum of man and the higher animals, called the *Corpora Striata;* and a thin layer of grey matter on their surface is the earliest trace of the more superficial part of the cerebrum, known as the *cerebral hemispheres* of more highly-developed brains. Next behind these are two much larger masses, called the *Optic Lobes,* because they are connected with the optic nerves, or nerves of sight, which are here seen passing forward and diverging from beneath the olfactory lobes. Behind the optic lobes is a single median mass, which is the *Cerebellum*, or little brain. A short piece of the *Spinal cord* is seen behind this, the upper, wider and thicker part of which, near the cerebellum, is the *Medulla oblongata.* It is from this part that the auditory and gustatory nerves, or nerves of hearing and taste, take their origin.

Lastly, there are nerves of common sensation, or feeling, and motor nerves, through which the various muscles are governed, arising from the base of the brain or sides of the medulla and spinal cord,—only a short piece of which latter is shown in the figure.

The component parts or masses of the fish's brain, therefore, are arranged in linear series, one behind the other, so that all are visible at once from the upper aspect. The cerebrum proper is a very insignificant mass; the optic lobes are the largest masses in the whole brain, and the entire organ, even its widest part, is not much broader than the spinal cord itself. Indeed, in one small and very lowly-organized worm-shaped salt-water fish, called the lancelet, or amphi-oxus, the spinal cord terminates at its anterior end in a narrow medulla oblongata, there being no nervous masses in front of it; and even in the lampreys, which are more highly organized, the proper cerebral masses are still very small.

In the Frog's brain, B, the same parts are seen as in the fish, viz. commencing in front, the little olfactory lobes, then the two proper cerebral masses, elongated from before backwards; next the optic lobes, each projecting laterally, and then the medulla oblongata, across which lies a little transverse fold of nervous substance, which is the only representative of the cerebellum. Here, then, in the batrachia, as compared with fishes, the cerebrum proper begins to predominate over the olfactory and optic lobes. In the reptiles, this is still more evident.

In the pigeon, C, the cerebrum is so large as to surpass and almost conceal the comparatively small olfactory and optic lobes, which parts are now situated not directly before and behind the cerebrum, but chiefly beneath it. The cerebrum even now is principally composed of the deep parts called the corpora striata; but there is a marked separation between them and the superficial stratum which forms the cerebral hemispheres. The cerebellum is a very important part, being composed of a large median laminated mass, having two smaller lateral masses connected with it, one on each side,—the medulla oblongata being almost hid by it in this view. In birds, therefore, the cerebrum and cerebellum show, in a decided manner, that preponderance in size and importance of parts which become still more marked in the different mammalia, and especially in man.

Thus in the Rabbit, D, the cerebrum is relatively still larger, and instead of being smooth on the surface of its hemispheres, it is marked by slight grooves, which are the earliest indications of the still more complex modelling to be presently noticed. The olfactory lobes project in front of the cerebrum, whilst, behind it, is a complex mass forming the cerebellum, now characterized by a greater development of its lateral masses, which are small in the bird, and also by its more closely laminated structure. Behind the cerebellum is the medulla oblongata prolonged to form the spinal cord. As to the optic lobes, they are no longer visible from above, being quite concealed by the enlarged cerebrum.

In the Cat, E, the cerebrum completely preponderates over the olfactory and optic lobes, nearly concealing the former and completely hiding the latter. In order to increase the extent of the cerebral hemispheres, their surface is now modelled into numerous nearly symmetrical folds, called *convolutions*, between which are well-marked furrows, named *sulci*. The cerebellum here also informs a very important laminated mass covering the medulla oblongata.

In the Sheep's brain, F, the cerebrum is still larger; its hemispheres have a still more complicated modelling on their surfaces, and they cover not only the whole of the optic and nearly all the olfactory lobes, but a considerable portion of the cerebellum also. Each hemisphere, moreover, presents a distinction on its under surface between the part called the anterior lobe and the rest.

In the Monkey, G, the cerebrum at length completely overlaps all the other masses, including the cerebellum; its convolutions are numerous and deeply marked, and the development of the surface of its hemispheres approaches, though it by no means reaches, the condition which it attains in man.

But it is in the Human Brain that the cerebral hemispheres reach their highest development in proportion to the other masses, extend further forwards and backwards over them, more completely conceal the now large cerebellum and even the medulla oblongata, and present the greatest complexity of surface.

Looking down on to the brain, nothing but these cerebral hemispheres can be seen, forming two continuous masses, separated from one another by a deep median or *longitudinal fissure*. On their under surface, fig. 4, *a*, and on each side, fig. 5, *a*, a deep curved fissure, named the *fissure of Silvius*, marks off the part called the *anterior lobe* from the part called the *middle lobe*, whilst, further back, the part corresponding with or overlapping the cerebellum, *b*, is named the *posterior lobe*. At the bottom of the longitudinal fissure the two hemispheres are attached to each other, though for a certain distance only, by a large transverse mass of white nervous substance, called the *corpus callosum*, fig. 6, *c*, again seen as a curved white surface, cut through vertically in fig. 7. This important transverse connection or *commissure*, as it is called, varies in extent in the different mammalia in accordance with the development of the hemispheres themselves; in the marsupial quadrupeds, birds, reptiles, batrachia, and fishes, it does not, properly speaking, exist,—the hemispheres being joined together towards their under surface only. Below the corpus callosum, as shown in fig. 7, each hemisphere is also attached to a stalk-like mass of white substance, called its *peduncle* or *crus* (the leg), which speedily unites with its fellow, both being then continued downwards into the medulla oblongata, fig. 4 and 7, *m*, which again is prolonged down as the spinal cord, *c c'*.

The cerebral hemispheres have been compared to the budding efflorescence at the summit of the stalk of a cauliflower. Their free or unattached surface at all points, viz. in front, behind, above, below, and at the sides—as shown in figs. 3, 4, and 5—and even within the Sylvian and the longitudinal fissures, fig. 7, *a*, is modelled into the *solid* folds called *convolutions* or *gyri*, which are separated by the *furrows* or *sulci*—the convolutions being far more numerous and complex, and the furrows deeper than in the brain of any of the lower animals. The depth to which the furrows penetrate and the solidity of the convolutions are seen in the horizontal section through the hemispheres, *a a*, fig. 6. It is also shown that the surface of the hemispheres, both on the convolutions and within the sulci, is everywhere composed of grey matter, *g*, whilst the interior consists of white substance. Deeply seated below the corpus callosum, within the white substance of the anterior lobes, are two grey and white masses, known as the *corpora striata*, which, as already stated, compose nearly entirely the cerebral lobes of fishes, batrachia, reptiles, and birds. Just behind these are two other masses of grey and white substance, embedded in the middle lobes, and named the *optic thalami*. Behind these, below the posterior part of the corpus callosum, and at the back of the cerebral peduncles, project four small roundish eminences, white externally and grey within, named the *corpora quadrigemina;* the two belonging to the right half of the brain being shown in profile in fig. 7, just in front of the divided cerebellum. Above them, next below the back part of the divided corpus callosum, is a little conical body, projecting backwards, called the *pineal gland*, which was considered by the old anatomists as the seat of the soul. The optic thalami and corpora quadrigemina together, from both of which parts the optic nerves arise, appear to correspond with the optic lobes of fishes. Many other parts of the cerebrum, which cannot be mentioned here, have received special names.

The *olfactory lobes* are reduced in man to two small oblong masses of grey substance, placed beneath the anterior lobes of the cerebrum, and connected with them by white tracts or bands. They are usually, but erroneously, called the olfactory *nerves*, for they are parts of the great nervous centre or brain, from which the true nerves of smell are given off. They are shown in fig. 4,—the left one being marked 1, whilst that belonging to the right half of the brain is seen beneath the right anterior lobe in fig. 7.

The *cerebellum*, marked *b*, is shown in three different aspects; viz. from beneath in fig. 4, from the side in fig. 5, and cut vertically down the middle line in fig. 7. It is of very great size in man; it consists of two broad lateral masses or hemispheres, fused together by a narrower central mass. Each hemisphere is divided into lobes, which again are split into numerous thin parallel portions called *leaves* or *laminæ*, which everywhere consist of grey matter on the surface, penetrated by white substance from within, so that they present on a section, fig. 7, a beautiful branched and foliated appearance, which has received the name of *arbor vitæ*, or tree of life. In the white centre of each hemisphere is a folded mass of grey matter, named the corpus dentatum. The cerebellum is united to the cerebrum, through the corpora quadrigemina, only by slight *ascending peduncles* of white substance,—to the medulla oblongata by larger *descending white peduncles*, whilst its two hemispheres are joined by very massive white *middle peduncles*, which blend into a mass called the *pons Varolii*, or bridge of Varolius, embracing the peduncles of the cerebrum, just above the medulla oblongata. The under surface of the pons is seen, marked with transverse lines in fig. 4, and as cut through in the vertical section, fig. 7.

The *medulla oblongata*, figs. 4 and 7, *m*, and the *spinal cord*, figs. 4 and 5, *c c'*, and fig. 7, *c*, of which the medulla appears to be merely the enlarged cranial portion may be described together. They both consist externally of white substance continuous with the peduncles of the cerebrum and the descending peduncles of the cerebellum, and of a quantity of grey substance occupying their interior, though these are arranged differently in the two. Neither in man nor in animals generally does the spinal cord reach the whole length of the vertebral canal; and though it varies somewhat in the different classes in its relative form, size, and length, yet its fundamental structure is the same. The most remarkable differences in form which it presents depend on the presence or absence of limbs, and on their size when they exist. Thus, in serpents, which have no limbs, the cord is of uniform, or nearly uniform, diameter throughout; whereas in animals with limbs, it presents decided enlargements, involving an increase of both white and grey matters opposite the origins of the nerves of those limbs. In man, the spinal cord, figs. 4 and 5, presents a cervical and a lumbar enlargement, from which the great auxillary and lumbo-sacral bundles of nerves marked *ax* and *l*, *s*, arise; and as it extends only as low as the first lumbar vertebra, the origins of the lumbo-sacral nerves have to pursue a very long course within the vertebral canal before they escape at the intervertebral foramina. The lash of white strings thus formed is called the *cauda equina*, or horse's tail. Amongst them is a central filament, prolonged from the tip of the spinal cord down to the inside of the sacral canal, which is called the *central ligament* of the cord, and serves of course to steady it during the movements of the trunk.

In fig. 8, A, is seen a cross section of the spinal cord, showing the curious arrangement of the grey matter within it, by which, each half of the cord, partially separated from the other by *median fissures* in front and behind, is marked off into parts named *anterior*, *lateral*, and *posterior columns*, between which the grey matter penetrates in the form of two *horns* or *cornua*. In the medulla oblongata, these cornua are no longer traceable,—the grey matter being more broken up or diffused. It possesses, however, a separate mass of grey matter on each side, interposed in the course of the anterior columns, which gives rise to an external oval bulging called the *olivary body*, shown in fig. 4. The collections of grey matter which give origin to the auditory and gustatory nerves are also found in the medulla,—the former in its posterior, the latter in its central part.

The cerebro-spinal nervous axis, or brain and spinal cord,—the parts of which have just been described, consists of two lateral and, like the body generally, symmetrical parts, intimately joined together by median tracts of white substance called commissures. From the complex involution of certain parts of the brain, there result curiously-formed spaces in its interior, named the *ventricles of the brain*, the sides of which, smooth and moistened with a thin fluid, touch each other. They were formerly but fancifully regarded as "chambers for the animal spirits." One purpose they serve in the admission of blood-vessels into and from the interior of the encephalon.

From the base of the cerebrum, and from the sides of the medulla oblongata and spinal cord, spring numerous white cords, called the *cerebro-spinal nerves*, which are equally symmetrical with the great nervous centres from which they arise, and are distributed laterally to all parts of the body. Together with those centres, they complete the cerebro-spinal nervous system. Some of them, arising from the cerebrum, medulla oblongata, and upper part of the spinal cord, pass to their destination through holes in the base of the cranium, and are hence called *cranial* nerves, of which there are nine on each side, or *nine pairs*, as they are called, fig. 4, 1 to 9. The rest, arising from the spinal cord, and escaping through openings in the sides of the vertebral canal, are called the *spinal nerves*, of which there are, on each side, *thirty-one pairs*. The bundles of white threads by which the nerves arise are called their *roots*. Most of the cranial nerves commence by one bundle or root; but the spinal nerves have two distinct sets of bundles, springing from the sides of the cord, called, from their position, the *anterior* and *posterior roots*. These, which are seen in fig. 4, and also in the section B, fig. 8, *n*, join together in the intervertebral foramen, to form a common nerve-trunk. The posterior root has a small mass of grey matter, or a ganglion upon it, which, as already mentioned, is believed by some to belong to the sympathetic system.

Protective Membranes of the Brain and Spinal Cord.

The brain is of course protected by the cranium, and the spinal cord by the vertebral column,—the former being therefore lodged in a bony case, having immovable walls, whilst the latter occupies the greater part of a comparatively flexible canal.

The cerebrum, as shown in fig. 5, which may be compared with fig. 3, diagram No. 1, completely fits into the upper and larger part of the cranial cavity, extending from the roof of the orbits, back to opposite the occipital protuberance; whilst the cerebellum and medulla oblongata lie in the smaller region below. As already stated, the spinal cord extends only as low as the first lumbar vertebra.

It must not be supposed, however, that the soft and tender substance of the brain and spinal cord is in immediate contact with the bones of the skull and vertebral canal, for it is invested and protected in a most admirable manner by three kinds of membranes or coverings; viz. an external tough *fibrous membrane*, next to the bones, called, from its firmness, the *Dura Mater*, an internal *vascular membrane* next to the nervous substance, named the *Pia Mater*, and an intermediate *serous membrane*, composed of two layers which line the dura mater and cover the pia mater, and called, from its web-like delicacy in certain situations, the *Arachnoid Membrane* (αραχνη, a spider).

a. In the cranium the dura mater adheres closely to the bones, acting here as their internal periosteum, helping to hold them together, and smoothing down or padding, as it were, all the sharp eminences and hollows of its hard unyielding internal surface, against which the brain has indirectly to rest. The dura mater also sends off two strong fibrous expansions, which project into the cavity of the skull, incompletely dividing it into three great chambers. One of these incomplete partitions is horizontal, and stretches across between the cerebellum and the posterior lobes of the cerebrum, see fig. 5,—being attached to the rest of the dura mater at certain ridges found on the inner surface of the occipital and temporal bones. This, which is called the *tentorium*, or *tent*, is seen on the right side in fig. 3, diagram No. 6,—the left half being cut away in making the section through the head. The other partition, *f*, in the same figure is median and vertical, and penetrates between the right and left hemispheres of the cerebrum, down to the corpus callosum, ending on the floor of the skull in front and on the tentorium behind: from its sickle-like shape, it is called the *falx major*. There is a very slight median projection of the dura mater below the tentorium, opposite the depression between the hemispheres of the cerebellum: this is the *falx minor*. It is obvious that the falx major and tentorium must steady and support the great nervous centres in the various movements of the head, prevent one cerebral hemisphere from pressing on the other in lateral motions or recumbent postures, and bear off the weight of the cerebrum from the cerebellum in the upright attitude. In the cat tribe, in which sudden and powerful springing movements are so frequently performed, the tentorium is not membranous, but bony, as if still further to obviate the effects of shock.

Along the attached borders of the falx and tentorium, at the free border of the former, and along the line where the one rests on the other, the dura mater splits so as to leave open channels, which, lined with an epithelium, form *veins* or *venous sinuses*, for conveying the blood returning from the brain,—the circulation through which is facilitated by this arrangement, as the walls of such channels cannot be compressed except in case of injury or disease. One of these sinuses, named the great longitudinal sinus, is marked *v* in fig. 3, diagram No. 6; others exist at the back part and base of the skull. The sinuses discharge their contents chiefly into the internal jugular veins of the two sides.

In the *spinal canal*, fig. 5, the dura mater is not adherent to the vertebræ, which have each their proper periosteal covering; but it forms a wide tubular sheath, extending along the spinal canal, as low as the end of the sacrum, placed at a little distance from the bones, and having between it and them much loose, areolar, and fatty tissue, besides plexuses of veins. This sheath is shown in the section of the cord and its membranes, fig. 8, B, *m*. It is obvious that such an arrangement was necessary to permit of the requisite mobility of the vertebræ one upon the other in the performance of the movements of the spine; whilst, as already stated, within the cranium, the dura mater is attached directly to the bones, and forms their internal periosteum.

Lastly, the dura mater presents many little tubular processes, which pass through the several foramina at the base of the skull and sides of the vertebral column, and form protecting sheaths for a short distance around the cranial and spinal nerves, fig. 8, B, *n*.

b. Within the cranium, the innermost membrane of the brain, or pia mater, fits closely to the surface of that organ, passes into the several fissures, into the sulci between the cerebral convolutions, and between the laminæ of the cerebellum, and in some situations penetrates the ventricles of the brain. Wherever it covers the grey nervous substance, as on the cerebral hemispheres and the cerebellum, it consists of a close network of blood-vessels, held together by delicate areolar tissue. Besides directly inclosing and supporting the soft nervous substance, it forms a matrix, like the periosteum for the bones, in which the larger blood-vessels ramify or break up into a network of finer vessels, from which those which penetrate at all points the tender structure and safely and effectually supply it with its nutrient fluid, are given off,—the force of the circulation being thus modified, and the distribution of the blood itself equalized throughout.

Upon the white surfaces of the brain, viz. the peduncles of the cerebrum, the pons, and the medulla oblongata, and also upon the spinal cord, the pia mater rests closely, and supports small vessels, which ramify in it before giving off those which enter the white substance; but these are not so numerous as in the case of the grey matter, and the pia mater itself is thinner but firmer and less vascular.

When the sheath formed by the dura mater for the cord is laid open, there is seen on each side of the cord, as shown at one part in fig. 4, a strong but thin transparent membrane, passing from the whole length of the cord to the dura mater, to which it is fixed, at intervals only, by an outer toothed or serrated edge. This, which is a sort of process from the pia mater, is called the *denticulate ligament.* It supports or suspends the spinal cord in its median position during lateral bendings of the trunk; whilst the central ligament, already described, which may also be regarded as a prolongation of the pia mater from the tip of the cord down to the inside of the sacral canal, not only steadies the cord in its place, but being somewhat elastic, assists in restoring it to its ordinary position when the trunk is erected, after having been bent forwards. It is further obvious that both the denticulate and central ligaments, in thus restraining within due limits the movements of the cord, save the delicate bundles which form the roots of the spinal nerves from extension and laceration.

Finally, the pia mater furnishes to the nerves, as they lie within the cranium and spinal canal, a thin investment, which is continued along them as their proper coat or *neurilemma.*

c. The serous membrane, called the arachnoid, consists, like the pleura, pericardium, and peritonæum, of a visceral and a parietal layer,—the visceral layer investing the brain and spinal cord being loosely connected with the pia mater, and the parietal layer lining the dura mater, with which it is intimately blended. These two layers are continuous with each other, at certain points, as along the nerves, so that the arachnoid forms a closed sac, the inner surfaces of which touch each other, but are free, smooth, and moistened with a serous fluid.

Although the pia mater closely follows the convoluted and variously-modelled surface of the brain, the arachnoid does not; hence there exists between them, opposite the sulci, and especially opposite the depressions on the uneven base of the brain, certain intervals, named *sub-arachnoid spaces,* which communicate freely with a similar sub-arachnoid space, existing between the arachnoid and the pia mater of the cord, as seen in the section B, fig. 8. A very thin albuminous fluid, which may pass from one part of these spaces to another, according to circumstances, is called the *cerebro-spinal* fluid.

The arachnoid must facilitate such movements of the nervous centres as are impressed upon them by the inflections of the head and vertebral column, or by other causes. Moreover, the existence of the cerebro-spinal fluid in all interspaces not occupied by the nervous substance, by the blood-vessels and their contained blood, or by the membranes themselves, provides a sort of fluid-couch or hydrostatic bed for the brain and spinal cord. Furthermore, there seems reason to conclude, that either by displacements of this fluid between the cranium and spinal cord, or else by slight distensions of the membranes at the cranial or intervertebral foramina, or else by actual change in the quantity of the fluid, accomplished by rapid secretion or absorption, such differences in the amount of blood in the cranio-vertebral cavity as are inevitable in certain conditions during life, are compensated for without any undue or injurious variations of pressure upon the nervous centres.

The amount of design exhibited in the use of the three membranes which surround the great nervous centres, is altogether very striking.

The Cranial and Spinal Nerves.

a. The *Cranial Nerves*, fig. 4, 1 to 9, as already stated, consist of nine pairs, which are arranged and distributed symmetrically on the two sides of the body.

The *first* or *olfactory nerve*, fig. 4, 1, the nerve of smell, is connected by three small bands of white substance with the anterior and middle lobes of the cerebrum, and ends in front in a swelling or knob called the *olfactory bulb*, from which branches perforate the roof of the nose in the manner represented and described in diagram No. 8, fig. 12, 1.

The *second* or *optic nerve*, the nerve of sight, arises chiefly from the optic thalami and corpora quadrigemina, winds round the peduncle of the brain, and joins its fellow in the middle line, forming the *optic commissure.* From this, the right and left nerves pass forward, and entering the orbits, are given to the eyeballs, as shown in diagram 8, fig. 21, *n n.*

As the third, fourth, and sixth nerves all enter the orbit, and are distributed to the muscles contained therein, they may next be described.

The *third* nerve, 3, also called the *motor oculi*, or mover of the eye, arising out of the cerebral peduncle, supplies the muscle which raises the upper eyelid, and four muscles belonging to the eyeball, viz. the superior straight muscle, diagram No. 8, fig. 21, 1, the internal straight muscle, 3, and the inferior straight and the inferior oblique muscles, —neither of which latter are shown in that figure.

The *fourth* nerve arises from the back of the cerebral peduncle, around which it winds to pass forward to the orbit. It is the slenderest of the cranial nerves, and runs the longest course of any within the cranium; it supplies only one muscle of the eyeball, viz. the superior oblique, trochlear or pulley muscle, 4. Hence it is called the *trochlear* nerve, and sometimes the *pathetic* nerve, because the muscle which it controls is supposed to give such an expression to the eye. It is said also to send filaments to the lacrymal gland, or gland which secretes the tears.

The *sixth* nerve, arising from the upper limit of the forepart of the medulla oblongata, supplies only the external straight muscle, diagram No. 8, fig. 21, 2, and is named the *abducent* nerve, because it governs the muscle which abducts or turns outwards the eyeball.

As the first and second cranial nerves supply sensitive parts only, they are called *sensory nerves;* whilst such nerves as the third, fourth, and sixth pairs, which are distributed to muscles, and are concerned in the manner hereafter to be pointed out in exciting muscular contractility, are called *motor nerves.*

The fifth *cranial* nerve, 5, next to be described, is a *mixed nerve*, that is, both sensory and motor. It commences by two portions or *roots*, which appear separately at the side of the pons Varolii, but really come from the medulla oblongata. One of these roots, the smaller, has been shown to be the motor portion, whilst the other and larger root is sensory. The sensory part becomes connected with a mass of grey matter, the *Gasserian ganglion*, and then splits into *three divisions*, with only the lowermost of which the motor root, having passed beneath the ganglion, joins.

The *upper* and *middle* divisions of the fifth nerve, named respectively the *ophthalmic* and *superior maxillary nerves*, derived from the sensory root only, give off numerous branches, which supply the soft parts within the orbit, including the eyeball and the lacrymal gland, also the cavity of the nose, as shown in diagram No. 8, fig. 12, 5,—the palate, the gums and teeth of the upper jaw,—and lastly, the skin upon the forehead, eyelids, nose, cheeks, and upper lip,—forming the nerves of common sensibility, or the nerves of touch, for all those parts.

The lowermost division of the fifth nerve, called the *inferior maxillary nerve*, which is the mixed portion of the nerve, supplies motor branches to the muscles of mastication, viz. the temporal, masseter, buccinator, and pterygoid muscles, and gives sensory branches to the tongue, to the teeth and gums of the lower jaw, and the skin of the lower lip and lower part of the face,—being the nerve of common sensibility to those parts. The branch given to the tongue, however, is also concerned in the special sense of taste as well as the common sense of touch, and hence it is called the *gustatory nerve*.

From its division into three great parts, the fifth nerve is also called the *trigeminal nerve*, and from its supplying the face, the *trifacial nerve*. Its three facial branches finally issue from three foramina in the bones, shown in diagram No. 1, fig. 1, above and below the orbit and in the lower jaw; they then immediately divide into numerous twigs to supply the skin of the forehead and face, as represented in the central figure of the present diagram, 5, 5, 5.

The *sixth* cranial nerve has already been described.

The *seventh* nerve, fig. 4, 7, on each side, consists, like the fifth, of a sensory and a motor portion, but in this case they do not unite, for each pursues a distinct course.

The sensory part, which, from its soft texture, is called the *portio mollis*, is a nerve of special sense, the nerve of *hearing*, or *auditory nerve*. It arises from the back of the medulla, and passes into the internal auditory opening in the temporal bone (see diagram No. 1, fig. 3, and p. 6), and is then distributed to the deep parts of the ear, as shown in diagram No. 8, fig. 18, *n*.

The motor part, arising from the side of the medulla, called, from its firmness as compared with the auditory nerve, the *portio dura*, and also named the *facial* nerve, as it supplies the muscles of the face, enters the same opening in the temporal bone as the portio mollis, and having pursued a remarkable course through that bone, escapes from the skull under cover of the mastoid process, and perforating the parotid gland, divides upon the margin of the lower jaw, as shown in the present diagram, fig. 9, 7, into numerous branches, which form what is called the *pes anserinus*, or goose's foot, and are ultimately distributed to the muscles of expression in the face, viz. those of the external ear, forehead, eyebrows and eyelids (except the levator of the upper eyelid, which is in the orbit), nose, and lips. It also supplies two muscles going down to the hyoid bone. Its smaller twigs interlace freely with those of the trifacial nerve. One remarkable branch of the facial nerve, called the *chorda tympani*, because it crosses through the drum or tympanum of the ear, appears to be distributed in part to the sub-maxillary and sub-lingual salivary glands. Probably, the facial nerve itself gives branches to the parotid gland.

The *eighth* nerve, fig. 4, 8, consists on each side of three divisions, which being in part sensory and in part motor, form together a mixed set of nerves. The two upper divisions arise from the side of the medulla oblongata, and the lowest from that and from the side of the spinal cord in the neck. All three escape from the same foramen at the base of the skull, and so gain the neck. The two upper divisions have ganglia upon them. The upper or highest division, called the *glosso-pharyngeal* nerve, is certainly almost wholly, if not exclusively, a sensory nerve, and is distributed, as its name implies, to the tongue, that is, to the back part and sides of that organ, and to the pharynx, as well as to the soft palate and tonsils. It appears to be partly the nerve of common sensation for the mucous membrane generally, but partly also a nerve of special sense, seeing that it is concerned in the transmission to the nervous centres of certain sensations of taste. Besides this, the glosso-pharyngeal supplies a few muscles about the pharynx; but this, its motor character, may be due to its previous junctions with other nerves.

The middle and largest division of the eighth, called the *pneumo-gastric nerve*, because its principal destination is the lungs and stomach, is, at its origin, essentially a sensory nerve, but soon derives a motor character also from its communication with the succeeding division of the eighth nerve. The trunk-line of this nerve descends behind the great blood-vessels of the neck, fig. 9, 8, passes down into the chest behind the root of the corresponding lung, 8, thence continues downwards on the œsophagus, 8, with which it perforates the diaphragm, *d*, and is finally distributed upon the walls of the stomach, 8,—the left nerve ending upon the front, and the right on the back of that organ.

In the neck, besides communicating with other nerves, the pneumo-gastric supplies branches, motor and sensory, to the muscles and mucous membrane of the pharynx and larynx. One to the latter organ, ascending to its destination, is named the *recurrent* laryngeal nerve. Below this it gives off branches, which, with the sympathetic nerves, supply the trachea, bronchi, and lungs, especially the mucous membrane of those parts. It also concurs with the sympathetic to afford the necessary nervous supply to the heart. Finally, it sends branches to the whole length of the œsophagus, and even a few twigs to the stomach, which join the sympathetic nerves of the liver and intestines. The pneumo-gastric nerve therefore, in its motor capacity, governs the vocal apparatus and entrance to the air-tubes; whilst, as a sensory nerve, it conveys to the nervous centres the impressions which give rise to the sensations peculiar to the respiratory organs, and those belonging to the œsophagus and stomach. It is also a principal channel of nervous communication between the cerebro-spinal nervous centres and the heart. From their extensive distribution, these important nerves have received the title of *par vagum*, or the wandering pair of nerves.

The lowest and smallest division of the eighth nerve is named the *spinal accessory nerve.* It arises from the side of the spinal cord, and ascends into the cranium, in order to pass out with the rest of the eighth nerve. It is principally, perhaps entirely, a motor nerve. Part of it, the *accessory* nerve, joins the pneumo-gastric nerve, and thus doubtless contributes motor fibres to the muscles of the larynx; whilst the rest, the *spinal* part, descending the neck, is distributed to the sterno-mastoid and trapezius muscles (diagram No. 2, fig. 1).

The *ninth* nerve, the last of the cranial set, arises from the front of the medulla, and escaping through the base of the skull, arches downwards and forwards in the neck, fig. 9, 9, to reach the under side of the tongue; whence its name of *hypoglossal* nerve (ὑπο, under, and γλωσσα, the tongue.) It is the motor nerve which supplies the muscular substance of the tongue.

Of the cranial nerves, all but the special nerves of smell, sight, and hearing, have communications with the sympathetic system, and the small ganglia connected with the roots of many of them are regarded by some as sympathetic ganglia.

b. The *Spinal Nerves* consist of *thirty-one pairs*, given off, as shown in fig. 4, from the sides of the spinal cord, *c c*. Each arises by an anterior and posterior bundle of white cords called a root. The anterior root is motor, and the posterior, sensory; the denticulate ligament, *t*, of the cord is placed between them. In each nerve (see diagram No. 9, fig. 40), the sensory root has a grey ganglion, by some regarded as a sympathetic ganglion. Beyond this, the motor root joins the sensory, and the mixed nervous trunk thus formed escapes from the spinal canal at the corresponding intervertebral foramen, as shown in the lumbar region, fig. 9, *l*.

The *eight* upper spinal nerves coming out of the spinal canal in the neck are called the *cervical nerves;* to these succeed *twelve dorsal nerves* in the back; next are *five lumbar nerves* coming out at the loins; below these are *five sacral nerves;* and lastly, there is a *single coccygeal nerve.* Of these, the upper cervicals, the dorsals, the upper lumbars, the lowest sacral, and the coccygeal, are comparatively small, and so are the portions of the cord from which they arise, because the parts which they supply, viz. the neck and the walls of the trunk, are small; but the lower cervicals are much larger, and the lower lumbar and upper sacral nerves are the largest of all, as well as the corresponding parts of the cord, because they have to supply the upper and lower limbs. The long course pursued by the roots of the lumbar and sacral nerves within the spinal canal, and the mode in which they form the lash of nerve-cords named the *cauda equina*, has already been explained.

The four upper cervical nerves of each side, appearing in the neck, interlace to form the *cervical plexus* (see fig. 9), from which motor branches proceed to the neighbouring muscles, including the occipital muscle; whilst sensory branches are given to the skin on the hinder half of the head, the external ear, the neck, and the top of the chest and shoulder. From this cervical plexus also a very remarkable branch, called the *phrenic nerve*, *p* (on the right side of fig. 9), descends behind the clavicle and ribs into the chest, and passing downwards, as shown in the case of the left nerve, *p* (on the left side of fig. 9), in contact with the pericardium,—which has been removed to exhibit the heart—reaches the diaphragm, which it penetrates, and is then distributed on the under surface to the muscular fibres. It is the proper motor nerve of the diaphragm. Some slender connections which it forms here with the sympathetic nerves of the liver are sometimes regarded as in part explaining the pain felt in the shoulder from disease of that organ.

The four lower cervical nerves, together with the first dorsal nerve, interlace to form the *axillary* or *brachial plexus*, *ax*, figs. 4 and 9, which gives off sensory branches to the shoulder, the upper part of the chest, and the upper limb,—especially to the skin of those parts,—and motor branches to the muscles of the shoulder, arm, forearm, and hand.

In the left arm of the central figure, the large deep-seated nerve-trunks are seen accompanying the main blood-vessels along the inner and protected side of the limb, sending branches to the several muscles. The *median nerve*, marked *m*, *m*, besides giving muscular branches in its course, ultimately supplies the palm of the hand, the thumb and fingers, as far as the outer half of the ring finger; whilst the *ulnar nerve*, *u*, *u*, supplies the muscles adjacent to it, and then ends in branches for the inner half of the palm and ring finger, and for the little finger. The median and ulnar nerves are, therefore, the nerves of touch, as specially exercised by the fingers and hand. The ulnar nerve, as shown in the diagram, passes close behind the lower end of the humerus or arm-bone, between it and the projection of the ulna at the elbow. When the nerve is accidentally struck at this part against the bone, a well-known shock, accompanied by a tingling sensation extending down along the course of the nerve to the little finger, is produced. The inner condyle of the humerus, though in point of fact, quite passive in the affair, is hence popularly termed the *funny bone.*

In the right arm of the figure, the cutaneous nerves, or those which supply the skin upon the outer side and back of the arm, fore-arm, and hand, are seen perforating the fascia at various points, and then lying upon it, in company with the superficial veins. Of course, both here and elsewhere, only the more obvious branches are represented, for the ultimate twigs are invisible without the aid of the microscope.

Of the twelve dorsal nerves, the first, as already stated, joins the brachial plexus; but it also supplies the first intercostal muscle. The remaining eleven dorsal nerves are called *intercostal nerves*, because they run along the spaces between the ribs, the last, however, being below the last rib. They are seen in fig. 9, two of them being referred to by the letter *i*. Like the rest of the spinal nerves, they communicate with the sympathetic system; but they do not interlace with one another to form a plexus. They supply the proper muscles of the walls of the chest, the lower ones escaping from beneath the cartilages of the ribs to gain the muscles on the sides and front of the abdomen. They also give off the cutaneous branches of the trunk.

The four upper lumbar nerves interlace to form the *lumbar plexus*, figs. 4 and 9, *l*, from which branches are given off to the muscles and skin of the lower part of the front of the abdomen, to the muscles and skin only upon the hip, the outer side of the thigh, to the hip- and knee-joints, and to the skin only upon the hip, the outer side of the thigh, and the inner border of the leg and foot. On the right thigh, in the centre figure, the superficial cutaneous nerves of the fore part of the limb are seen lying upon the fascia, together with branches of the superficial veins. In the left limb are seen certain deep-seated nerves, derived from the lumbar plexus; viz., the *crural nerve*, *c* (from *crus*, the leg or thigh), which splits into numerous branches, some of which become cutaneous, whilst others accompany the great blood-vessels; also the *obturator nerve*, *o*, *o*, which comes out from the pelvis through the obturator foramen (see diagram No. 1, p. 11), gives off branches to the hip-joint and to the neighbouring muscles, and then, after interlacing with twigs from the crural nerve, appears to assist in supplying the knee-joint. Hence, disease in the hip-joint is often accompanied by a so-called sympathetic pain in the knee, though no positive mischief exists in the last-named joint.

The last lumbar and four upper sacral nerves unite to form the *sacral plexus*, figs. 4, 5, and 9, *s*, from which, the muscles of the gluteal region, those at the back of the thigh, and all those of the leg and foot are supplied with motor nerves; and from which also proceed sensory nerves, especially those supplying the skin of the back of the hip and thigh, the front, outer side, and back of the leg, and the back and sole of the foot. Some of the cutaneous branches, perforating and then ramifying upon the fascia, are shown on the right limb. Of the deep-seated branches of the sacral plexus, by far the largest (and indeed, by far the largest nerve in the whole body) is the *sciatic nerve*, fig. 5, *n*, fig. 9, *sc*. Passing out at the back of the pelvis, it runs deeply amongst the muscles behind the thigh-bone into the ham, giving off branches as it proceeds. One of these, the *posterior tibial nerve*, *t*, is displayed in the left leg, lying beneath the dissected muscles of the calf, and passing behind the inner ankle to dip into and supply the parts in the sole of the foot.

The sciatic nerve is the seat of that most painful neuralgic disease, *Sciatica.*

It remains only to add, concerning the common sensory branches both of the cranial and spinal nerves, that though these are chiefly intended for the sensitive surfaces of the body, viz., the skin and adjoining parts of the mucous membranes, yet that to all parts of the system, however feebly sensitive, sensory nerve-branches find their way; as, for example, the *fascia*, *tendons*, *ligaments*, synovial membranes of the joints, and even the bones. Some of the nerve-fibres of the muscles bound up with the proper motor nerves, must also have a sensory office, conveying to the sensorium information concerning the state of the various parts of the muscular system.

The microscopic *structure* of the soft and tender grey and white substances of the brain, spinal cord, and cerebro-spinal nerves, will be described in diagram No. 9,—the grey matter consisting of oval or branched nucleated cells, shown in figs. 42 to 48, and the white substance being composed of distinct but very delicate tubular fibres, represented in figs. 38, 39 of that diagram.

The nerves consist essentially of tubular fibres, gathered into larger and smaller fasciculi or bundles, which are surrounded and supported by a membrane, derived from the pia mater of the brain or spinal cord, and called the *neurilemma* (see fig. 38, diagram No. 9). It is important to remember that along the nerves the white fibres continue *distinct* from each other in their whole course. The fibres of the nerves of special sense, viz., the olfactory, optic, and auditory, are somewhat finer than the rest; but those of the sensory and motor portions of the nerves generally are quite undistinguishable from one another. In most of the nerves, a very few gelatinous fibres derived from the sympathetic system are intermixed.

Functions of the Cerebro-Spinal Nervous System.

In the cerebro-spinal, as in the sympathetic system, the grey masses are to be regarded as the centres of nerve force, either active or reacting, whilst the white fibres, wherever found, are merely conductors, laid down like telegraph-wires, to convey impulses or impressions in certain definite directions.

The grey matter, as will have been gathered from preceding pages, occupies the centre of the spinal cord, permeates in a more diffused manner the interior both of the medulla oblongata and the cerebral penuncles, is found in certain masses inside the cerebellum, and at the base of the cerebrum,—as in the corpus dentatum, corpora quadrigemina, optic thalami, and corpora striata,—forms a continuous layer on the outside of the cerebellum, and finally, is accumulated in by far its largest quantity, and especially in the human brain, on the convoluted surface of the cerebrum.

As to the white fibres, they constitute the trunks and branches of the cranial and spinal nerves, both sensory, motor, and mixed. They form the outer strata or columns of the spinal cord, medulla oblongata, cerebral and cerebellar peduncles, a large proportion of the internal substance of the cerebellum, a very large share of the interior of the cerebral hemispheres, and lastly, the whole of the corpus callosum, which connects those hemispheres together. Within the great nervous centres, however, the exact course of the white fibres has, as yet, baffled investigation, though much has been learned by dissection, and the examination of microscopic slices of the brain and spinal cord, hardened in alcohol or other fluids which act chemically on the white substance.

From such researches the following general points have been determined. First, many of the white fibres in the substance of the brain and spinal cord are the deep continuations or *true roots of the* various *nerves* springing from those parts. Secondly, others pass from one grey mass to another, on the same side of the cerebro-spinal axis, running *longitudinally* in the cord,—some connecting this, through the medulla oblongata and the cerebral peduncles with the grey masses at the base of the cerebrum, and these again by radiating fibres with the cerebral hemispheres,—others forming longitudinal commissures in the cerebrum itself,—and lastly, others passing from the medulla to radiate into the cerebellum. Thirdly, another set, still longitudinal in their general direction, decussate, as it is called, or cross each other *obliquely* in the middle line, at the *forepart of the medulla oblongata*, and may be traced upwards and downwards into the brain and spinal cord; so that the right half of the latter, with its nerves, is partly in connection with the left half of the former, and *vice versâ*,—an arrangement of the highest importance in a functional point of view. Fourthly, there are groups of *transverse* fibres,—such as the corpus callossum, pons Varolii, and other commissures, which connect corresponding parts of the right and left halves of the cerebro-spinal axis and the roots of its various nerves together across the middle line. When all the minute details of this intricate arrangement, which undoubtedly follow a general plan, and probably are constant in the different species of animals, are known to us, the sources and paths of different nervous actions will be better understood than they are at present.

Functions of the Cranial and Spinal Nerves.

It will have been noticed, from the descriptions already given, that the nerves are of three kinds; viz., purely *sensory*, purely *motor*, and *mixed* sensory and motory, according as they convey sensory impressions to the censorium or brain, or conduct some regulating or controlling influence from the nervous centres to the muscles, or participate in both those offices. It has also been shown that the first, second, and soft portion of the seventh cranial nerves are sensory,—ministering to the functions of smell, sight, and hearing; that the third, fourth, sixth, hard portion of the seventh, and ninth cranial nerves, are motor, serving to govern the muscles of the eyeball, forehead, face, and tongue; that the fifth and eighth cranial nerves are of a mixed character,—ministering to the function of taste,—serving to endow the skin and mucous membranes, and, indeed, the soft parts generally of the head, face, throat, and air-passages, with common sensibility, and the lungs, heart, and stomach with their peculiar or special sensibilities,—and also helping to govern the muscles of mastication, those of deglutition, those of the larynx or organ of voice, and certain of the superficial muscles of the neck; and lastly, that the spinal nerves are all mixed sensory and motor nerves, which supply the remainder of the sensitive and muscular tissues of the body. It has been further noted, that, whereas all purely sensory and purely motor nerves commence by a single root or set of roots, the mixed nerves arise by two distinct roots or sets of roots, of which one is motor and the other sensory, which afterwards unite to form a mixed trunk. Finally, it has been stated that, in regard to microscopic structure, all the nerves, whether sensory, motor, or mixed, are essentially alike, the only difference being in a greater degree of fineness of the fibres of the nerves of special sense.

How, then, have the different properties of the roots, trunks, and branches of the cranial and spinal nerves, been so accurately explained? This has been done by observing the results of injury or disease in man, and of experimental irritation or division of the nerves in living animals; and, indeed, as these vital cords, with their individual characters, and in certain cases their very remarkable duplex origin, are, as it were, ready-analyzed or separated parts of the nervous system, the knowledge thus obtained, taken in conjunction with the at present ascertained anatomical relations of the various nerves with particular portions of grey substance in the brain and cord, has further led to important inferences concerning the functions of those grey masses themselves.

If a nerve of common sensation,—such as the frontal division of the fifth, fig. 9, 5, above the orbit, or if the sensory root of a mixed nerve,—such as a spinal nerve, be pinched or irritated in a living animal, *pain* will be produced, accompanied or not by certain movements of a peculiar kind, called *reflex* movements, which will be hereafter explained. If a motor nerve,—such as the facial, fig. 9, 7, or the motor root of a mixed, say a spinal nerve, be irritated, *no pain* will be produced; but *convulsive movements* will take place in the muscles to which the nerve is distributed. If the trunk of a mixed nerve,—such as any spinal nerve, be pinched, both pain will be produced and movements be directly excited in the muscles supplied by that nerve.

Again, when a sensory nerve, whether of special or common sensation, is cut through, the part or organ, to which that nerve belongs is rendered quite insensible,—division of the optic nerve causing blindness, and that of the nerves running along a finger, total insensibility to touch. When a motor nerve,—such as the facial, is cut through, then the muscles supplied by that nerve can no longer be moved by the will, or by any other impulse originating in the nervous centres, although contractions from direct irritation of the nerve or muscles may take place. When a mixed spinal nerve, or a given branch of such a nerve, like the median of the arm, fig. 9, *m*, is divided, all the parts supplied by it below the place of division are *paralysed*,—the sensitive parts losing their sensibility, and the muscles being absolved from all control. Furthermore, when the sensory and motor roots of a mixed nerve are separately divided one after the other, the corresponding functions of sensation and muscular control are separately and successively annihilated in the several parts to which that nerve is distributed.

If now that end of the divided sensory nerve, or the divided sensory root of a mixed nerve which is still in connection with the nervous centres, be pinched or otherwise irritated, every time that this is done, provided that the nerve yet retains its vitality, there is produced pain or the sensation proper to the nerve, with or without movements of a reflex kind; but, on the other hand, irritation of that end of the divided sensory nerve or sensory root, which is cut off from the nervous centres and remains in connection only with the organ or part it supplies, produces no sensation whatever. Again, if that part of a divided motor nerve or motor root of a mixed nerve, which remains in connection with its muscle, be pinched or otherwise irritated, the muscle instantly undergoes contractions, which may thus be again and again induced, so long as all the parts retain their vital endowments;

but if the end of the motor nerve which is in connection with the nervous centres be irritated, neither movement nor pain is produced. Finally, if the thus *attached* and *detached* parts of a mixed nerve are irritated, conformable results ensue; namely, pain in the former case, with or without reflex movements, and local movements without sensation in the latter.

The phenomena which follow disease or injury of the nerves in man, whether dependent on irritation, pressure, wasting, or actual severance of parts, are altogether in accord with those resulting from experiments on animals; and it is worthy of note, that when the cut end of a sensory nerve is irritated in the human body, the pain or sensation is referred to the parts naturally supplied by that nerve, as is observed after amputations of the arm or leg, when, even long after the stump is healed, the subjects of those operations feel pains which they refer to their lost fingers or toes.

Taken together, observation and experiment not only demonstrate the functions of particular nerves or their roots, but they prove that, in the exercise of those functions, the nerve-fibres act merely as *conductors*, which require continuity for the due performance of that office, and which, during life, have no sensibility, and no governing power over muscular tissue, unless they are in connection with the grey substance of the cerebro-spinal axis.

In the living body, therefore, the sensory fibres may be regarded as commencing in the sensitive parts, and ending in the grey matter of the brain or cord; whilst the motor fibres, on the other hand, commence in certain parts of the grey matter of the brain or cord, and end in the muscular system. The mode of commencement of the sensory nerve-fibres is illustrated, in regard to the skin, in diagram No. 8, fig. 4, *n;* whilst one way in which they end amongst the muscular fibres, that is, *by loops*, is shown in fig. 10 of the present diagram. As to their mode of connection with the grey matter, some appear merely to pass amongst the nucleated cells of that substance, whilst others end by joining the branch-like processes of certain of those cells.

The sensory fibres conveying impressions *inwards*, or centripetally, to the nervous centres, are called *afferent* fibres; the motor fibres, conveying impulses *outwards*, or centrifugally, from the nervous centres, are named *efferent*. The afferent fibres of the various sensory nerves are impressed each by their appropriate stimulus, the optic nerve by light, the auditory by sonorous undulations, the olfactory by odorous particles, the gustatory by sapid substances, and the nerves of touch by contact with matter, chemical agents, heat, and so forth; whilst the efferent fibres of the motor nerves are stimulated by volitional, emotional, or, as they are called, reflex stimuli, acting in and from the grey nervous centres.

The nature of the conducting power of the nerves, or the mode in which the various impressions from without and impulses from within are conveyed or conducted along them inwards and outwards, is not known. It is conjectured, however, that in ordinary action some change of state—of the nature of which we are quite ignorant, yet which we may conceive to be accompanied by certain established physical conditions, chemical, electrical, molecular, and polar—takes place at the outer or peripheral ends of the sensory fibres, and at the inner or central ends of the motor fibres; and then that such change of state is itself rapidly propagated, or propagates some farther change along the nerve-fibres, progressing towards the nervous centres in the case of a sensory nerve, and towards the muscular substance in the case of a motor nerve. When, during an experiment, some part of a nerve, or the ends of a divided nerve, are irritated, it is possible that the impressions so produced upon its fibres may be propagated in both directions; but, in the case of the sensory fibres, can produce no appreciable sensations in the peripheral part away from the nervous centres, and in that of a motor nerve no appreciable phenomena in the central part in connection with the nervous centres; but such supposition is quite consistent with the conclusions already stated, that in the ordinary mode of action, the sensory fibres are practically afferent, and the motor fibres efferent conductors—the former inducing their proper effect, *sensation*, in the nervous centres, the latter, their proper effect, *contraction*, in the muscular system. These two remarkable phenomena are amongst the unsolved riddles of animal physiology; for we are equally ignorant of the mode in which the supposed changes in the sensory fibres act on the grey matter in inducing sensation, and of the way in which the supposed changes in the motor fibres affect the muscular substance so as to cause contraction. And of the still higher and unapproachable mysteries of the mode in which matter and spirit are so linked together that, through the intervention of the grey matter the immaterial principle becomes conscious of sensations, and the will excites volitional impulses, we are, and, we may almost assure ourselves, shall ever remain, absolutely without knowledge.

Finally, concerning the motor nerves and the motor roots of mixed nerves, it has to be added, that though their distinctive character is truly motor, they appear to receive from the brain or spinal cord a few intermixed sensory fibres; for when they become inflamed after injury or division, any further irritation of their *attached* ends produces pain. This property is called their *recurrent sensibility*.

So, again, as regards the common sensory nerves, and the sensory roots of the mixed nerves, it appears that, as already alluded to and as will hereafter be fully explained, these may, under certain circumstances, convey to the grey matter of the nervous centres impressions which do not produce sensation, though they may be associated with it, but which are *reflected* by the grey matter along the motor nerves, and so excite remarkable muscular movements, totally independent of the will, called *reflex movements*. The occurrence of such movements suggests the probability of there being certain afferent and efferent fibres in the sensory and motor nerves specially devoted to the production of these acts.

Functions of the Spinal Cord.

In the first place, the spinal cord is the *medium of connection* between neighbouring nerves on the same side of the body, and, by means of its transverse commissures, between those of opposite sides, thus serving to bring into harmonious action different parts of the spinal system.

In the second place, it can be shown that, as far as regards sensation and volition, the spinal cord is merely a large *conductor* acting like the mixed spinal nerves themselves in conveying sensory impressions and volitional impulses to and from some higher part of the cerebro-spinal axis. That the spinal cord is not the seat of conscious sensation, nor of will,—or, in other words, that the impressions conveyed inwards by the sensory nerves are not converted into sensations within it, and that volitional impulses do not emanate primitively from it, is proved by the fact that if it be injured, compressed, or wasted by disease at one point in man, or cut across in animals, all the organs or parts of the body supplied by nerves arising below the seat of injury are deprived of sensibility, and freed from voluntary control. Moreover, by experimental irritation of its various columns, and partial divisions of their substance in animals, it has been shown generally that the posterior columns of the cord on each side of the median fissure, are essentially concerned in conducting sensory impressions, whilst the lateral and anterior columns are the essential channels of volitional impulses,—corresponding in this manner respectively with the functions of the posterior and anterior roots of the spinal nerves, arising from those parts.

As to the mode in which the cord exercises this conducting power, much remains to be determined. Formerly it was supposed that it depended on the white sensory and voluntary motor fibres of the nerves being prolonged upwards through the cord, the medulla oblongata, and the cerebral peduncles, to the great sensorial and volitional centres in the cerebrum; but, as already mentioned, it is now believed that only a few of the nerve-fibres can so ascend, for most of them appear to interlace or end in the grey matter of the cord, from and within which others would seem to ascend as conductors to and from the brain. It has further been concluded from experiments, that, though the white substance of the posterior columns may conduct sensory impressions for a short distance into the cord, it is the grey portion itself of those columns (which, however, it must be remembered, is for the most part permeated by white fibres) which transmits or reflects the sensory impressions upwards to the brain; and the same experiments appear to demonstrate that the paths of these sensory impressions speedily decussate or cross to the other side of the cord, so that the grey matter of the right posterior column conducts the impressions made on the left side of the body, and *vice versâ;* for division of one half of the cord, though followed by loss of muscular power of the same side, causes loss of sensibility on the opposite side.

Finally, it has been shown that, as the motor nerves possess a recurrent sensibility when they are inflamed, so do the anterior columns of the cord, some time after they have been divided, convey feeble sensory impressions.

As to the exact path of the voluntary motor impulses, it would seem to be chiefly the white fibres of the anterior and lateral columns; but also, to a certain extent, the subjacent horn of grey matter, in which white fibres are mixed up. These motor channels do *not* decussate in the cord, but in the medulla oblongata higher up.

c. In the third place, the spinal cord is endowed with the remarkable property of transmitting or reflecting impressions made upon it in such a manner as to give rise to very definite muscular movements, which may be excited quite independently of any action of the cerebrum, and therefore are not necessarily associated with sensation or volition. Such movements have been frequently referred to in the preceding pages as *reflex movements.* (See the account of the action of muscles, p. 23, of the respiratory and allied movements of the chests, pp. 44–5, of the movements of deglutition, p. 92, and also pp. 132, 134 of the present diagram.)

The existence of this independent function, the *reflex function,* as it is called, of the spinal cord, has been inferred from the results of observation on man and of experiments on animals. Thus, when the tail of a growing tadpole or of a newt, into which the spinal cord extends, is divided, it is evident that the severed portion of the animal must be altogether beyond voluntary control, and there is reason to believe is destitute of sensibility or feeling also. Yet, if it be now pinched or pricked, it will exhibit movements which appear frequently to have for their end or object to get rid of the cause of irritation. Again, if the spinal cord of a frog be divided in the neck or the frog be decapitated, volition, and we are entitled to say, sensation, is lost in all the parts supplied by nerves given off below the line of division, yet if the skin, say of the side or abdomen, be now pinched or pricked, energetic movements will occur, and that one of the limbs which is most convenient for the purpose will even attempt to seize and remove the irritating instrument.

The integrity of the portion of the spinal cord severed from the rest is an essential condition to these results; for after it has been destroyed by a fine wire being thrust down the spinal canal, although this step be accompanied at the moment by general convulsions in all the muscles supplied from it, no movements whatever will take place on irritating the skin as before. Besides this, the sensory nerves of the skin irritated and the motor nerves of the muscles which are to contract, must be uninjured and connected with each other, through the intervention of the cord itself. When this necessary chain of connected nervous parts is complete, some impression appears to be conveyed from the surface touched along the so-called *afferent* fibres, which it can be shown by further experiments pass through the sensory roots of the nerves, into the grey portions of the cord; there it produces *no sensation*, but is reflected in some way, so as to *excite* a motor impulse, *not volitional*, which travels through the motor roots along so-called *efferent* fibres to the muscles intended to act. Hence these reflex movements are also called *excito-motory*. Precisely similar movements may and do occur in perfect animals and in man.

The part taken by the nucleated cells of the grey matter in this function is not exactly known; whether they receive from certain white fibres and transmit to others the necessary stimulus, or whether the white fibres concerned merely run between the nucleated cells. As to the afferent and efferent white fibres, it is natural to conjecture that, though bound up with the sensory and voluntary motor fibres, they are arrested in the cord and have no connection with the brain; for we know that most of the fibres of the nerves do not and cannot ascend to the brain, otherwise the cord would become gradually larger from below upwards, and be much thicker at its upper end than it really is.

It is not disputed by any that these spinal reflex movements are entirely *involuntary*. In the warm-blooded animals and in man this is quite certain; so also in decapitated cold-blooded animals, although the more extensive spinal reflex movements excited in them by irritation are decidedly *combined* to certain purposes,—as in thrusting away an irritating body, or in drawing up a limb into position under the body when it has been previously extended,—there is reason to conclude that they are equally beyond the influence of will, for the creature will continue perfectly motionless until it dies, so long as it remains untouched. But some have felt disposed to repudiate the notion that these movements are unaccompanied by *sensation*, arguing that sensibility is a general attribute of the grey nervous matter of the cerebro-spinal axis, and that some share of it must exist in the spinal cord during its connection with the cerebrum, even though it may, as it were, retreat from or be lost to the cord when this is severed in experiments. But consciousness also is essential to sensation, or, as it may be expressed, a sensation is not recognizable or realized without consciousness, and as this latter faculty can hardly be supposed to be divisible, or capable of acting beyond its usual seat, the brain, direct proof must always be wanting that sensations necessarily accompany these movements. Practically, too, there are instances of spinal reflex movements in the human subject, which occur without sensation; for in cases where, in man, the spinal cord has been so compressed or injured in the dorsal region as to be followed by complete insensibility as well as loss of voluntary power in all the parts below, the application of galvanism to either of the lower limbs will produce involuntary reflex movements, absolutely without any sensation, and even without the knowledge of the injured person. So, too, in profound sleep, or in the state of insensibility called coma, tickling the feet, nose, eyelids, or ears, will produce movements which are certainly reflex, and apparently do not produce any complete or conscious sensation, although it might be urged that in such cases there is sensation unregistered by memory.

It is, however, now generally admitted that the spinal reflex movements are essentially independent of sensation; and yet when the spinal cord is in its natural state of connection with the brain, such movements are often associated with feeling, in which case, besides the excito-motory impressions, those which are necessary to sensation are supposed to be conveyed by certain afferent fibres into the spinal cord, and thence in some manner to the brain itself. Thus, in the ordinary waking state, when the nervous apparatus is perfect, galvanism or tickling will produce movements identical, as regards effect, with those just described as reflex, but which are necessarily accompanied by more or less sensation.

d. The involuntary convulsive twitchings of the muscles often seen after severe lascerations or burns, are many of them of a reflex character. In other cases, too, as in poisoning by strychnine, in hydrophobia, tetanus, epilepsy, and the convulsions from teething in children, there seems to be a peculiarly excitable condition of the reflex apparatus,—sometimes manifesting itself only on the application of a stimulus or local cause of irritation, but sometimes also producing convulsive or spasmodic involuntary movements directly as a consequence of the morbid state of the reflex nervous centres themselves,—under which denomination are to be included, not only the spinal cord, but its prolongations upwards, the medulla oblongata, the deeper portions of the pons Varolii, and the cerebral peduncles.

e. That constant state of readiness to contract, or tendency to contract, which gives what is termed "*tone*" to the muscular system, seems also to depend in some way on the integrity of the nerves and the grey matter from which they arise. It is immediately lost after destruction of the spinal cord and its prolongations up to the base of the cerebrum.

f. The intimate connection between the cerebro-spinal system and the sympathetic has already been pointed out (p. 116); and there appears to be special evidence, from experiments on animals, to show that the spinal cord, amongst other nervous centres, exercises a decided influence on the action of involuntary muscular parts which are principally supplied by the sympathetic system. Thus it is found that powerful irritation by galvanism of the dorsal portion of the spinal cord, or of the splanchnic nerves (which contain spinal nerve-fibres), instantly *arrests* the peristaltic action of the intestines, which, as it continues after all the nerves upon the mesentery are divided, seems to be regulated by intrinsic sympathetic ganglionic corpuscles, such as in the case of the ox have been found in the submucous intestinal coat. So, likewise, the rhythmic beats of the heart, which are undoubtedly regulated by intrinsic cardiac ganglia, are *lowered* in frequency by powerful stimulation of the pneumogastric nerves, or of the cervical portion of the spinal cord. On the other hand, it is found that very weak stimuli similarly applied *increase* the action of the intestines and the heart. The depressing action in the first-named experiments is, however, a very positive result, and has led to the term "*inhibiting influence*" being applied to this apparent property of the spinal cord.

There are many facts which would seem to prove the existence of a similar influence exercised by other parts of the cerebro-spinal axis on the proper sympathetic movements. Thus, violent struggling in animals has been seen to be followed by cessation of the intestinal movements, and by some interference with the heart's action; sudden destruction of the brain of a frog causes the heart to stop for a short time; acute pain or violent emotion will occasion arrest or failure of the heart's action; and, lastly, fear may give rise to a choleraic attack.

Even in regard to the power of the sympathetic to regulate the nutritive and secreting functions through the conditions of dilatation or contraction of the blood-vessels, as already alluded to at p. 116, the spinal and cerebral nervous centres exercise an influence which also may be viewed, under certain circumstances, as "inhibitory," if we take into account its effects. Thus, a mild stimulation of the nerves of a frog's foot will produce contraction of the arteries of the web; but a powerful stimulation of the same nerves causes those vessels to become dilated. Again, division of the spinal cord, limited to one side,—though immediately productive of loss of sensibility on the opposite side of the body, because the channels of sensory impressions decussate in the cord,—is, after a short time, followed by increased sensibility in parts situated on the same side; and this, it is likely, is owing to some influence on the sympathetic nerves of that side, by which their power of keeping the blood-vessels in a state of contraction is interfered with or "inhibited," and the parts accordingly become first congested and then inflamed, and therefore more sensitive. Again, when the sympathetic nerves supplying the submaxillary gland, and the branch from the facial, named the chorda tympani (see p. 126), which also sends branches to that gland, are cut across in a dog, and the portions of those nerves still in connection with the gland are alternately stimulated by galvanism, it is found that dilatation of the blood-vessels, an increased flow of blood through the gland, and a large quantity of a watery secretion, are the results of irritating the chorda tympani, whilst a like stimulation of the sympathetic branches is followed by contraction of the vessels, a diminished flow of blood through them, and a more scanty but thicker secretion. On irritating the chorda tympani, the phenomena are once more reversed, and so on. In this experiment the power of the sympathetic over the contractility of the blood-vessels is contrasted with that of the cranial nerve, the influence of which seems to suspend that of the sympathetic nerve on the vessels; and as a result of this, a more abundant and watery saliva is formed, although there may not be more salivary substance secreted. Irritation of the back of the medulla oblongata in some way increases the glycogenic power of the liver, and causes the appearance of the redundant sugar in the renal excretion. Perhaps the watering of the mouth, at the sight or thought of food, is due to some inhibitory influence exerted on the sympathetic through that part of the cerebral centre which is exercised in the formation of ideas. The flow of saliva during mastication may indicate a similar influence accompanying the powerful action of the surrounding muscles; and the flow of tears, which are secreted by the lachrymal glands situated in the orbits, on the occurrence of certain emotions of joy or grief, or from simple suffering, may be due to a similar influence of an emotional or sensational kind, acting through the emotional or sensorial nervous centres in the brain. It has indeed been recently shown that the fourth cranial nerve sends a branch to the lachrymal gland; and through this, some such inhibitory influence may possibly be exerted, as leads to an increased quantity of lachrymal secretion. The influence of the mind on the quantity of other secretions may be similarly explained; and, lastly, the phenomena of blushing may also be due to the inhibition of the ordinary action of the sympathetic nerves on the larger and smaller arteries of the face, by some fleeting mental emotions, stirring through the brain.

Functions of the Medulla Oblongata, of its Prolongations through the Pons Varolii, and of the Cerebral Peduncles.

The general functions of these parts are of the same character as those of the spinal cord, but they are of more importance as being absolutely essential to life. The medulla oblongata also contains the grey masses which participate in the special sensations of *taste* and *hearing*.

a. These parts serve to connect together the corresponding cranial nerves of opposite sides, and at the same time bring those which arise from the same side into connection with a considerable portion of the nervous centres, and so associate them all functionally.

b. Secondly, they act, like the cord itself, as conductors of sensory impressions passing up to the cerebrum, and of voluntary motor impulses passing downwards. The central or deep-seated grey and white portions of the medulla and peduncles are the chief sensory channels, which having, as already stated, decussated in the spinal cord, undergo no further change in that respect. The anterior white portions are the essential voluntary motor channels, and these do decussate entirely, in a most remarkable manner, in the fore-part of the medulla oblongata, by five or six bundles which pass across obliquely from one side to the other, and so form the *decussation of the pyramids*. Hence all injuries to the motor apparatus above the decussation cause a loss of voluntary control of the muscles on the opposite side of the body; whilst those below the decussation produce a similar result on the same side of the body.

The lateral and part of the posterior portions of the medulla oblongata also serve as conductors to bring the afferent and efferent systems of the spinal cord into connection with the cerebellum.

c. Thirdly, the medulla and its prolongations up to the base of the cerebrum are concerned in reflex functions of a most complex character, and of far more consequence to the animal economy than that of swiftly drawing away a part from some cause of irritation or endeavouring to remove the annoying object; for they maintain and regulate, by a process which makes no demand on the fatiguing watchfulness of our attention or on the capricious action of our will, many occasional or continuous movements, indispensable for the protection of delicate organs, the performance of important functions, and the preservation of life itself. A few examples must here be adduced:—

a. The common and so frequently-repeated act of *winking*, by which the eyeballs are kept moist, is a good and simple example of a reflex movement. The ophthalmic division of the fifth nerve, fig. 9, 5, furnishes afferent fibres, and the facial, 7, the efferent fibres,—

certain parts of the medulla being the connecting nervous centre between them,—whilst the orbicularis palpebrarum surrounding the eyelids is the muscle which performs the movement. It is usually almost entirely unaccompanied by sensation; but at other times, the dryness of the surface of the eyeball is a cause of perceptible discomfort.

β. The act of *sucking*, as first performed by the infant and by young animals, appears to be reflex, for it is then at least involuntary, and is done at once perfectly and without those previous trials and experiences, which are found necessary to the due performance of voluntary acts. Sucking is also often performed during sleep; and it has been seen to occur in young acephalous or brainless monsters amongst animals, and in persons completely comatose or insensible from pressure on the brain. Like other reflex movements, however, it may be, and usually is, accompanied by sensation.

γ. The second and third stages of *deglutition* (p. 91) are also reflex, and accompanied or not, according to circumstances, with some indistinct sensation. The grey matter concerned in regulating the former of these acts is seated in the medulla oblongata, the excitor nerve being chiefly the glosso-pharyngeal, and the motor nerves chiefly the pharyngeal branches of the pneumo-gastric, which probably are derived on each side from that part of the spinal accessory nerve which joins it. If the glosso-pharyngeal or afferent nerve be laid bare in an animal and pinched, or if it be cut through and its upper end irritated, movements of swallowing are immediately performed by the animal involuntarily,—a decisive proof of the reflex character of this stage of deglutition. The branches of the fifth nerves given to the soft palate may also furnish excitor fibres; and the motor root of the same nerves, and also the facial, hypoglossal, and certain cervical nerves contribute motor fibres to regulate the associated actions of the muscles of the throat generally in swallowing. The third stage of deglutition may also be in part a reflex act, performed through the agency of the medulla and of afferent and efferent fibres contained in the œsophageal branches of the pneumo-gastric nerves; but it is, perhaps, also in some measure governed by intrinsic sympathetic ganglia, like the peristaltic action of the intestines; for regular downward movements have been observed to occur in the œsophagus, after the division of all the nerves which go to it. The same remarks apply to the muscular movements of the stomach, including the action of those of the fibres which close the œsophageal orifice and of those which compose the pyloric valve.

δ. The ordinary *respiratory movements* (see p. 41) are purely reflex, being entirely performed without the interference of the will, it is evident enough in the waking state, but particularly so during sleep. The pneumogastric nerves—the sensory nerves of the lungs—contain afferent or excitor fibres, which proceed to the grey matter of the medulla oblongata, from which, and from the adjacent part of the cord, efferent or motor fibres pass chiefly along the spinal accessory, phrenic, and intercostal nerves to the muscles of ordinary inspiration. The accumulation of venous blood in the pulmonary capillaries is believed primarily to excite the extremities of the pneumogastric nerves and in ordinary cases this is unperceived; but when the breath is held for a long time, the exciting cause produces an uneasy sensation, owing to its being then recorded also in the sensorial centre higher up. By some it is believed that the condition of the blood in the system generally may assist in producing, through proper afferent nerve-fibres, the necessary excito-motory influence on the nervous centres of the respiratory movements; and there are undoubtedly instances in which the nerves supplied to the skin perform such an office, as witness the gasping inspiration of a fainting or half-suffocated person, or a feeble new-born infant, when cold water is dashed on the face or body; and as is also seen in the embarrassed action of the chest caused by a sudden plunge into cold water or the shock of a shower-bath. Hiccough is a spasmodic movement of the diaphragm, probably of a reflex character.

The complete dependence of the respiratory movements on the medulla oblongata, and their reflex character, are proved by experiments of various kinds. When, in a frog, the brain and cerebellum are entirely removed above, and the spinal cord below, leaving only the medulla oblongata with its nerves attached, respiration is still performed; but when that part is destroyed also, or is wounded or divided in another frog or in any warm-blooded animal, respiration immediately ceases, and sudden death ensues. Division or compression of even that part of the medulla which joins the spinal cord, in a warm-blooded animal, breathing by aid of a diaphragm, stops respiration and kills almost instantly, as takes place in the pithing of a dog, by plunging a knife between the atlas and the occiput, and in cases of dislocation high up in the neck. The back part of the medulla oblongata, a certain portion of which has hence been termed the *vital knot*, *le nœud vital*, by a French physiologist, is essential to the respiratory acts.

ε. In the four instances of reflex action just mentioned, sensation may be an accompanying phenomenon or not. There is, however, a large class of reflex acts with which sensation is invariably and necessarily associated, and which, therefore, have been named *sensori-motor*, and sometimes *consensual* movements. Such are the sudden and uncontrollable flinching from treading on a burning-hot substance, from the dropping of sealing-wax on the finger, or from the sting of a wasp,—the irresistible winking and forced closure of the eyelids, when an insect or a particle of inert or acrid foreign matter gets, as it is said, into the eye,—the involuntary starting at a noise,—the acts of sneezing to drive out snuff or any stimulating substance from the nose, closing the entrance into the air-passages against an irritating gas, and coughing to expel any intrusive morsel of solid matter or of phlegm from the same part,—vomiting, produced by the inhalation of particular odours,—laughing, as the effect of being tickled,—and yawning from a sense of oppression or weariness.

Such reflex movements as these, it will be found on consideration, are of a very complex character, and being combined in a perfect manner to suit peculiar ends or purposes, have been sometimes named *co-ordinate* movements, though this is a term applicable to all movements which are regulated by nervous agency, whether reflex, consensual, or voluntary. The more muscles are employed in the execution of any of these movements, the larger share of the medulli-spinal nervous axis is involved in their regulation; and thus, as yawning, sneezing, coughing, vomiting, and laboured respiration, are far more complex acts than the snatching away of the foot or hand from being tickled or stung, so they certainly involve the cerebro-spinal axis further up into the very base of the brain; and it has been supposed that their co-ordination and their association with some sort of feeling may be due to their implication of the grey ganglionic masses, the functions of which we have next to consider.

Finally, it will not fail to be noticed, that amongst these reflex movements, whether or not of the consensual kind, are some which are known to us as *instinctive acts*,—such as those of sucking, swallowing, coughing, and starting. But the higher instinctive *faculties* certainly include emotional and intuitive as well as sensational elements.

Functions of certain Grey Masses in the Medulla oblongata, of the Corpora quadrigemina, Optic Thalami, Corpora striata, and Olfactory Lobes.

The masses of grey matter in the medulla, with which the nerves of taste and hearing are connected,—the grey substance of the corpora quadrigemina and olfactory lobes which receive the fibres of the nerves of sight and smell,—and the large grey masses named the optic thalami, with which, through the sensory channels of the spinal cord, medulla oblongata, and cerebral peduncles, all the nerves of common sensation in the body are brought into relation,—are evidently essential to the production of the phenomena of *special* and *common sensibility*, for irritation or removal of these parts in experiments on animals, and the effects of disease in man, impair or destroy the respective senses functionally dependent on their integrity. In the case of injury to the corpora quadrigemina, the impairment or loss of sight affects the eye of the opposite side; but it not so with the olfactory and auditory masses.

It is believed by some physiologists that these masses of grey matter at the base of the brain are the actual seats of sensation, or the places where the mind becomes cognizant of all sensory impressions; and hence they have been named the *sensory ganglia*. In support of this opinion it is urged, that when the cerebral hemispheres are so removed in animals as to leave untouched those ganglionic masses, the mutilated creatures have still manifested signs which seem to indicate sensibility;—for example, a bird has followed the movement of a candle with its eye, and rabbits have cried and given other signs of pain when hurt. Again it is said, that the development of these ganglia in the brains of different animals in the vertabrate series is generally proportioned to the activity of the senses in them; and further, that in the brains of the lowest class, fishes, there is very little grey matter besides these ganglia, in which the final reception of sensory impressions could be supposed to take place,—viz. only that thin layer which invests the corpora striata, and represents the cerebral hemispheres of animals higher in the scale.

By other physiologists, however, it is believed that in complete conscious sensation the cerebral hemispheres are themselves involved.

Leaving this point undecided, it is still quite certain that the ganglionic masses in question are essential to sensation, and are concerned in many even simple reflex acts,—such as the contraction of the part called the iris in the eye (see diagram No. 8, fig. 21, *i*) from excess of light, and the adjustment of the membrane of the drum of the ear (the same diagram, fig. 15, *d*), to suit the different intensity of sounds. They also seem to be implicated in the execution of the consensual or sensori-motor reflex acts already described; and their anatomical connections are quite consistent with this view, for they severally give off fibres which connect them with the motor apparatus of the cerebral peduncles, medulla, and spinal cord, and motor fibres are especially traceable up to the corpora striata which are in intimate relation with the optic thalami. Experiment also appears to prove this; for birds deprived of their cerebral hemispheres will, when irritated, manifest movements of this character.

It may further be remarked here concerning the consensual acts, that, though necessarily associated with sensibility, they are, like the more simple reflex movements, quite independent of the will; and therefore require no experience, judgment, or education, for their perfect execution. In this respect, as well as in their co-ordination to particular ends, they may be likened to some of the *instinctive* movements of the lower animals, both vertebrate and invertebrate; and we may here conveniently add, that whereas, in point of function, the spinal cord of the former, governing the general locomotive apparatus, is analogous to the longitudinal nervous cords of insects and other articulate tribes,—and the medulla oblongata with its continuations to the base of the brain, governing the respiratory apparatus, the muscles of mastication and deglutition, and, perhaps in part, the gastric movements, corresponds with the respiratory and gastric ganglia of the invertebrata generally,—so the large ganglionic masses at the base of the vertebrate cerebrum, may be compared with the invertebrate cephalic masses or sensory and co-ordinating nervous centres which govern their instinctive movements.

Of the functions of the entirely superadded parts in the vertebrate organization, the cerebellum and cerebrum, we have now to speak.

Functions of the Cerebullum.

Considered anatomically, this part of the brain has very slight connections with the cerebrum; whereas, as already mentioned, very large columns of white fibres attach it chiefly to the lateral and posterior columns of the medulla oblongata and spinal cord, whilst its two halves are intimately, and, no doubt functionally, associated by means of the transverse white fibres of the pons Varolii.

Looking to its comparative anatomy, it presents a gradually increased importance, both as regards size and structural complexity, from fishes up to man, in whom it is larger in proportion to the body than in any animal. It is, moreover, largely developed in those animals which are capable of executing very complicated voluntary movements requiring the associated action of many sets of muscles.

When the cerebellum is being gradually removed in birds, they display, first feebleness of movement, then irregular movements without harmony, and then they lose the power of springing, walking, standing, or flying. When a bird, from which this organ is entirely removed, is laid on its back, it cannot recover its former position; but sensation, memory, and will remain, for it does not lie in a state of stupor, but flutters, and even tries, though unsuccessfully, to avoid a blow. In such instances, then, the power of controlling or regulating complex acts seems to be variously disturbed or destroyed, though the desire or will to execute them remains. Disease and injuries of this part in the human subject have been followed by comformable results. It may be mentioned here, too, that division of one of the lower peduncles of the cerebellum connecting it with the medulla oblongata and cord, is followed by a falling down of the animal on the side opposite to the injury, and a curious rotation or rolling-over of the creature, which may continue for hours.

From these and similar facts, it has been inferred that one office of the cerebellum is to *combine* or harmonize to given ends *voluntary* movements of a complicated kind; and it is certain that in man, who possesses the most highly developed cerebellum of any living creature, the capacity to perform the most varied and delicately combined movements is almost without limit.

On the involuntary reflex and consensual acts, the cerebellum has not been shown to have any influence. It is not known how or by which of its parts the cerebellum exercises the above-mentioned office. The functions of the corpora dentata within it are not known; though they are probably different from, even if associated with, those of the external layer of grey matter. The phrenological doctrine concerning the use of the cerebellum or of some part of it is deficient in scientific proof.

In reference to the above-mentioned rotatory movements produced by injuries to the peduncles of the cerebellum, it may be added, that movements of a similar character follow injuries of the cerebral peduncles, probably from interruption of the voluntary control, which comes down from the cerebrum; they also follow injury to the optic thalami, or the corpora quadrigemina, in which latter case they perhaps depend on some impairment or derangement of the function of sight.

Functions of the Cerebrum.

It has already been stated that the enormously extensive and convoluted layer of grey matter on the surface of the cerebrum—which is the seat of its functional power—is connected by the central radiating white fibres of its hemispheres with the several ganglionic masses seated at its base; that through these masses it is brought into free communication with the peduncles, medulla, and cord, and with the nerves which arise from those parts; that within itself its two halves, and, indeed, different parts of each hemisphere, are brought into active concert with the rest, by important systems of transverse and longitudinal commissural fibres, and by others which pass from one convolution to another; and, lastly, that its connections with the cerebellum are very slight indeed.

It is a singular fact that wounds of the grey and white substance of the cerebral hemispheres occasion no pain. Hence it has been inferred, concerning the grey matter, that it is not itself the seat of sensation, and, concerning the central white fibres, that they are incapable of conveying ordinary sensory impressions downwards to the supposed or so-called sensory ganglia at the base of the cerebrum,—but that they are capable of conducting *other* and *peculiar* impressions, both upwards and downwards, from one collection of grey matter to the other.

It has further been shown that wounds of the cerebral hemispheres do not give rise to any muscular movements; and hence it would seem that mere mechanical irritation of the grey or white substance composing those parts cannot replace the proper cerebral motor impulses, whatever they may be, nor yet are those substances concerned in the production of reflex phenomena in the same way as the several parts of the nervous centres extending from the base of the hemispheres downwards.

When the cerebral hemispheres are entirely removed in a bird or rabbit, the animal no longer exhibits either memory or will. If untouched, it will remain quite still for hours; and although, as already explained, it is capable of performing reflex and consensual movements under the requisite kind and degree of stimulation, it immediately, when left alone, resumes and retains its condition of perfect quietude, as if it were in a profound sleep.

Whether sensations are really *felt* in the so-called sensory ganglia at the base of the brain, or whether, for that purpose, an act of consciousness, and the co-operation of the cerebral hemispheres are needed, it seems well established that these last-named parts are in a manner the storehouses of *remembered sensations*, which are themselves derived from impressions made upon the sensory nerves and their grey centres by external agents, or by changes within the body itself, and which, when subjected to consciousness or registered in the cerebrum, constitute the bases or starting-points of the higher mental processes.

Materially speaking too, the cerebral hemispheres are the parts of the nervous centres in which such sensations, operating from our earliest infancy, not only occupy the *memory* or are *recollected*, but call forth *instincts*, *intuitions*, or *beliefs*, excite *emotions* or *passions*, suggest *ideas*, become the subjects of *reason* and *judgment*, result in *knowledge* or *experience*, and lead to the exercise of *will*,—the bodily actions which may ensue, also through cerebral influences, consisting of either *emotional*, *ideo-motor* or *voluntary movements*.

The two extremes of this series of processes, sensational and volitional action, touch more nearly, so to speak, our corporeal nature; but even concerning these, the faculties of *feeling* and *acting*, we know not the mode in which the grey and white nervous substances are influenced by or influence their production. Far less can we determine the localities and modes in which the brain operates during the various intermediate stages of any concatenated mental processes. Without endeavouring, as the phrenologists have done, to assign to certain regions of the brain definite functional relations to a particular series of animal propensities, of moral qualities, and of perceptive and intellectual faculties,—perhaps insufficient to, perhaps inconsistent with, perhaps redundant in a true scheme of our psychical constitution,—we know at least that, in this the present state of our existence, there is a strict dependence of mind upon matter, and that the emotional, imaginative, and intellectual faculties have the brain as their corporeal organ,—double like the rest of the body generally, though the mind usually acts individually,—and exhibiting, both in the animal series, and in the human series, a development, in different instances, in general but not yet understood accordance with the character and activity of those faculties themselves.

The pitiable moral and mental darkness of the helpless idiot, accompanied by defective cerebral organization,—the exaltation or depression of the reasoning powers, ideas, and passions, produced by cerebral stimulants or sedatives,—the delirium or mania occurring from irritation or inflammation of the brain,—the loss of memory, reasoning power, and will, which follow concussion or softening of that organ,—and conversely the injurious effects on its structure produced by long-continued over-excitement of the moral, and over-tasking the intellectual powers, are sufficient evidences of the mutual inter-dependence of the mind and its bodily organ, the brain.

This great fact in our nature has a most important application in social and sanitary science,—especially in regard to education. It teaches us the practicability and responsibility of so training and exercising our sensational, moral, and intellectual qualities, that they may be assisted by the progressively improved state of their associated corporeal organ, and so become strengthened for the exercise of our highest calls and duties; and it urges us with all the force of an irresistible penal law, enacted against disobedience, to avoid over-exertion of the brain, and to keep our whole bodies healthy and vigorous, lest our minds become enfeebled with them.

Nor does this view involve any admission of the dreary dogmas of materialism; for though observation cannot discern, nor reason demonstrate the secret of the soul, yet each individual human being capable of inward reflection, and mindful of the teaching of revelation, is sooner or later possessed with an irresistible belief in the existence of a principle within himself—acknowledged and recognized in language as a *Spiritual Principle*,—dwelling in the material or natural body, employing the cerebral organs as the instruments by which it communicates with, understands and reacts on the external world, but itself having an origin, existence and nature, a relation to God, a responsibility and a destiny entirely its own, and being capable of surviving after the extinction of corporeal life permits its separation from its earthly and temporary tenement, the body.

It remains only, in reference to this great subject of the Physiology of the Nervous System, to consider what are the motor impulses which appear to originate in or are of necessity associated with the action of the grey substance of the cerebrum, and especially of its two hemispheres. These are of three kinds, dependent respectively on the emotions or passions, the ideas, and the will, regarded as the final, though often very rapid, determination of the judgment.

In the first place, the pure *emotional movements*, such as those of the muscles which produce the various kinds of facial and vocal expression, and those of the body and limbs which give rise to gestures characteristic of the several passions, and secondly, the *ideo-motor movements*, like those of smiling, laughing, weeping, or crying aloud, when pleasing, ludicrous, or depressing ideas pass through the mind, are essentially involuntary in their nature,—quite as much so indeed as the consensual, spinal reflex, or sympathetic reflex muscular movements. Like these too (excepting the movements regulated by the sympathetic only), they may be controlled by the will, and by dint of practice, as in the case of mimics and actors, may even be imitated exactly,—that is to say, provided that the muscles concerned in their production are in nervous connection with the voluntary motor apparatus, or, in other words, *can* be subjected to the will.

But the third and highest kind of movements dependent on the brain are themselves *voluntary*, that is, result from the volitional or voluntary impulse, which, acting in some mysterious manner through the grey matter of the cerebral hemispheres,—the throne of the will,—sends it various mandates downwards through the great subjacent nerve-stem and nerves to nearly all parts of the muscular system, and, as regulated or combined in sundry complex modes by the functional powers of the cerebellum already described, issues in the production of the most vigorous as well as the most delicate operations, governs the various locomotive acts, works or plays, offends and defends, gives rise to proper voice as distinguished from involuntary cries, modulates this under the direction of the ear into song, and to crown all, exercises, partly under the suggestion of some instinct or necessity and partly as the result of imitative acts, that remarkable control over the muscles of the human mouth, which has for its results, *speech* or *language*;—the peculiar gift of God to man as a social creature; the chief, direct, and ready reflection of human thought and feeling; the logical derivative of our intellectual operations; the exponent of our animal necessities, moral capacities and spiritual aspirations; the indispensable agent and record of our progress upon earth; the great lever of continuous civilization; the voice of love to our neighbour, and of thanksgiving and prayer to our Creator, Preserver, and Saviour.

THE ORGAN OF VOICE.

Figures 11 to 15.

The *Organ of Voice*, named the *Larynx*, is situated in the neck, at the top of the trachea and just below the root of the tongue. It is suspended, indeed, from the hyoid or lingual bone by ligaments and muscles, and may be seen and felt at the fore part of the throat, as a sort of prominence, which has been named the *pomum Adami*, or *Adam's apple*. See diagram No. 2, fig. 1, *c*.

A front view of the larynx is shown in diagram No. 3, fig. 1, L; a section through the middle line is represented in diagram No. 6, fig. 3, *l;* and a posterior view, seen on opening the pharynx behind, is exhibited in fig. 4, *l*, of the same diagram. From a comparison of these two last-mentioned views, it will be understood that the larynx is a hollow organ, and, in fact, forms part of the main air-passage leading from the mouth to the lungs, communicating with the pharynx just behind and below the root of the tongue, and opening into the tube of the trachea, or windpipe, *t*, below.

The larynx has a basis or framework consisting of four *cartilages*, held together by *ligaments*, and provided with several pairs of *intrinsic muscles*, passing from cartilage to cartilage, and moving these upon one another. Stretched across its interior from front to back, and attached to certain of the cartilages, are two *elastic* membranous *folds*, called the *vocal cords*, the free edges of which being thrown into rapid vibration by air driven between them from the lungs, sonorous undulations or sound-waves are thereby produced in the column of air itself, as is done by the vibrating metal tongues of an harmonium, and so give rise to the voice. The whole appartus is lined by a highly sensitive *mucous membrane*, which is studded at appropriate parts with *mucous glands*, by the secretion from which its surface is kept duly moistened. Besides this, the larynx has its *nerves*, *blood-vessels*, and *absorbents;* and moreover, it has connected with it several pairs of *extrinsic muscles*, some of which can draw it down, whilst others can raise it up towards and for a little way behind the hyoid bone, as invariably takes place in the act of swallowing.

These several parts are exhibited considerably enlarged in figs. 11 to 15 of the present diagram, No. 7,—fig. 14 being increased six diameters, and the other figures about three. The letters on all the figures correspond.

Framework of the Larynx.

Fig. 11 represents the left of the cartilaginous framework of the larynx, and also shows one of its intrinsic muscles.

Surmounting the highest of the incomplete rings of the trachea, *w*, is a strong annular cartilage, *c*, named the *Cricoid cartilage*, shaped something like a signet-ring, being much deeper behind than in front. It forms the lower part of the larynx.

Riding, as it were, upon the cricoid cartilage is the *Thyroid cartilage*, *t*, a broad cartilaginous plate, bent backwards at an acute angle along the middle line, so as to present a sharp and nearly vertical median ridge turned forwards in the throat, where it produces the pomum Adami. The lateral parts of this bent plate, diverging from each other (see fig. 13), partly embrace the cricoid cartilage; the hinder margins are prolonged at their four corners into little processes, the two upper ones serving for attachments to the hyoid bone, whilst the two lower ones are connected, by perfect little joints provided with ligaments, to the sides of the cricoid cartilage, on which the thyroid cartilage can be rocked backwards and forwards.

At the summit of the back of the cricoid cartilage are two little pyramidal cartilaginous pieces, placed side by side, named the *Arytenoid cartilages*, the position of the left one of which is shown by the dotted outline *a* in fig. 11. In fig. 12 the right one only is represented, whilst both are seen in figs. 13 and 14. They are articulated by special joints and ligaments with the cricoid cartilage, upon which they are made to perform certain remarkable swinging movements, to be hereafter noticed.

These four cartilages, viz., the cricoid, thyroid, and two arytenoid, are composed of a pure bluish-white cartilage or gristle. As life advances, they often become partly ossified. There is another leaf-like plate of mixed fibrous and cartilaginous tissue, or fibro-cartilage as it is called, belonging to the larynx, named the *Epiglottis*,—marked *e* in the figures,—which as already explained at pages 90 to 92, serves as a valve to protect the larynx from the accidental entry of food or drink in the act of swallowing.

Interior of the Larynx.

Fig. 12 is an interior view of the right half of a larynx, which is supposed to have been divided vertically in the middle line. It shows two of the incomplete rings of the windpipe, *w;* also the two cut surfaces of the cricoid cartilage, *c;* the single cut surface of the thyroid cartilage, *t;* the right arytenoid cartilage, *a*, resting on the back of the cricoid; and, lastly, the median section of the epiglottis, *e*.

All these parts, except the cut surfaces alluded to, are here represented as if covered in, and therefore partly concealed by the mucous membrane lining the larynx, and by the subjacent soft tissues. From the front of the right arytenoid cartilage, *a*, two folds of this lining membrane are seen stretching forwards to the hinder surface of the anterior part of the thyroid cartilage. The lower of these two folds, marked *v*, conceals a band of yellow elastic tissue, which passes forward from a little projection or process on the forepart of the arytenoid cartilage to the recessed part of the thyroid cartilage. It presents a thin, smooth, straight margin, and forms, as covered by the mucous membrane, the right *true vocal cord*, being one of the parts thrown into vibration in the production of the voice. Above this cord, is a long opening leading into a pouch or sac, called the *laryngeal sac*, in the walls of which are many mucous glands, whose secretion helps to keep the vocal cords and the adjacent parts moist. The existence of this sac also serves the purpose of keeping free the edge of the corresponding vocal cord, so that it may vibrate easily. The fold of mucous membrane which bounds the sac above is called the *false* vocal cord, inasmuch as it is not in any way directly concerned in the production of the voice. Higher up still, the mucous membrane extends from the arytenoid cartilage to the side of the epiglottis, and so forms the margin of what is called the *superior opening of the larynx*, which, as will be clearly understood on examining fig. 13, is the part closed by the epiglottis, *e*, during the act of swallowing.

The left half of the larynx of course includes precisely similar parts to those here exhibited as belonging to the right side.

Fig. 13 is a sort of bird's-eye view into the larynx from above, showing the passage leading into and through it. It exhibits the upper margin and inner surface of the thyroid cartilage, *t*, and also the right and left arytenoid cartilage, *a*; but the cricoid cartilage is concealed by these latter, and by the soft structures within the larynx. The superior opening of the larynx, limited by the mucous folds passing from the two arytenoid cartilages to the sides of the epiglottis, *e*, is clearly seen. Within these the eye is conducted to a narrow median slit, wider behind than in front, and bounded on its sides by the right and left true vocal cords, *v*. This narrow slit between the true vocal cords, which leads into the trachea, is named the *Glottis*. Outside these cords are two dark spaces, which are the orifices of the laryngeal sacs already mentioned,—the mucous folds forming the false vocal cords being outside these.

Fig. 15 is an internal view of the anterior half of the larynx, lined by its mucous membrane,—the line of section being supposed to pass vertically and transversely across the opening of the glottis and the rest of the vocal apparatus. It shows how the passage for the air coming from the lungs, viz., the trachea or windpipe, *w*, is narrowed sideways at the glottis or slit-like fissure between the margin of the vocal cords, *v*, which, even to their sharp projecting edges, are inclosed in the mucous membrane, and do not form separate or isolated cords, as their name might lead one to suppose. The situation and plan of the laryngeal sacs, from which, as already stated, mucus is supplied to moisten the vocal apparatus, and which further secure the clear projection of the parts required to vibrate, are also seen. Above these sacs are the false vocal cords, from which the passage for the air again widens as it passes up to the borders of the epiglottis, *e*, and its mucous folds.

Production of the Voice.

All the air used in respiration passes through the glottis on its way to and from the lungs. During ordinary breathing only a soft sound is produced by the air gently moving through this aperture, the true vocal cords being then wide apart, divergent posteriorly, and in a state of relaxation. For the production of vocal sounds or voice, these marginal cords of the glottis are rendered more or less tense, and are brought parallel and closer to each other, so that the air which is now purposely driven with greater force and rapidity between them from the lungs by the action of the respiratory apparatus causes vibrations in their thin tense margins, and being thence itself thrown into corresponding waves or undulations, vocal sounds are produced.

In accomplishing this, the expired air is forced from a tubular chamber through a narrow slit, on a principle something like that of a tongued organ-pipe or an harmonium. A very interesting imitation of the laryngeal vocal apparatus may be made by fixing on to the upper end of a wooden or metal tube about the size of the trachea, a very short piece of vulcanized India-rubber tubing of rather smaller diameter, the free end of which has its orifice compressed to form a slit like the glotis. When the margins of this opening are rendered more or less tense, and a current of air is forced in through the tube below, sounds of various pitch are produced, very like those of the human voice. Such an artificial larynx will enable an experimenter to investigate and determine some of the physical conditions necessary for the production of various sounds; but there remains as altogether inimitable the wonderful power of self-adjustment which all parts of the living larynx possess, through the intervention of its muscles and their connection, by means of the nerves, with the nervous centres. It is a remarkable example of the economy of nature, too, that the voice, and therefore articulate speech, are produced by the utilization of the respiratory apparatus and of the escaping current of effete air already used in respiration.

The part of the margins of the human glottis used in vocalization is the forepart situated in front of the anterior projections or processes of the arytenoid cartilages; for no vibrations can be produced in the posterior part bounded by these processes themselves, which is limited to respiratory purposes, and which continues open even in the production of the highest notes, when the vocal cords themselves are brought very close together.

Up to the age of fourteen or fifteen, there is little or no difference in point of size between the larynx of a boy and that of a girl; but subsequently the former grows proportionately larger, so that at last, in the adult male, the vibrating parts or vocal cords are necessarily longer than in the female. They are also undoubtedly thicker, perhaps even coarser in structure. From all these circumstances the adult male voice is stronger, louder, and of lower pitch than the weaker and higher vocal range accomplished by the female larynx.

The cause of the difference in quality of the voice, known as its *timbre*, is not well known; but it must undoubtedly be dependent on physical, that is to say, structural peculiarities in some part of the laryngeal apparatus.

The production of the different *notes* within the compass of any one individual depends upon alterations in the length and state of tension of the vocal cords, and on their degree of proximity or separation from one another. The higher notes require the vocal cords to be comparatively shorter, tighter, and more closely approximated together; whilst the lower notes demand opposite conditions. A high note, furthermore, implies greater rapidity in the movement of the air through the glottis; but the quantity of air passing is larger during the production of a low note.

The volume or *loudness* of the voice depends mainly on the combination of quantity of air with greater force of expulsion. Loudness, with clearness, also demands a peculiar resonance up in the nasal cavities and sinuses. Lastly, the unnatural or *falsetto* voice seems also to be produced by some tensive change effected in the upper part of the pharynx at the back of the nose: hence it is called by singers the *head voice*, in contradistinction to the ordinary, or *chest voice*.

The Muscles of the Larynx and their Action.

The above-mentioned changes in the condition of the vocal cords, in their length, their degree of tension, and their state of approximation to each other, on which the different shapes and sizes of the glottis depend, are all effected by the varied co-operation of the intrinsic *laryngeal muscles*. These, which, with one exception, exist in pairs, are represented in figs. 11 and 14. Their anatomy and physiological action are deserving of minute attention.

On the front and sides of the larynx is one pair named the *crico-thyroid muscles*, which pass obliquely backwards and upwards from the cricoid to the thyroid cartilage. The left muscle of this name is marked 5 in fig. 11.

Fig. 14, which is on a larger scale than the others, exhibits the remainder of these little muscles, some of which are placed within, and some on the back of the larynx. In this figure, as in fig. 13, the parts are supposed to be viewed from above; but the mucous membrane is entirely dissected off. It shows the upper border of the thyroid cartilage, *t*, small portions of the upper border of the cricoid cartilage, *c*, and the arytenoid cartilages, of which the left one is marked *a*. The elastic bundle which forms the right vocal cord, *v*, is dissected out from the adjacent soft parts, and is seen to be attached in front to the thyroid, and behind to the corresponding arytenoid cartilage.

The muscles are as follow:—First, the right *posterior crico-arytenoid* muscle, 1, which passes upwards from the back of the cricoid cartilage to the base of the corresponding arytenoid cartilage. The fellow muscle is seen on the left side. Secondly, the *arytenoid* muscle, 2, consisting of bundles which pass from one arytenoid cartilage to the other, presenting an example of a muscle passing across the middle line of the body. Thirdly, the right *lateral crico-arytenoid* muscle, 3, which passes from the side of the cricoid backwards to the corresponding arytenoid cartilage. Fourthly, the left *thyro-arytenoid* muscle, which passes from the recessed angle of the thyroid to the corresponding arytenoid cartilage, and is placed in contact with the outer surface and lower edge of the vocal cord of its own side.

In considering the actions of these muscles, let us first examine how they effect the lengthening and tightening of the vocal cords. When the crico-thyroid muscles, fig. 11, 5, contract, they must draw the thyroid cartilage forwards and a little downwards upon the cricoid cartilage; or if the thyroid cartilage be supposed to be fixed, they would pull the cricoid backwards, and upwards from it. In either case, the arytenoid cartilages, connected as they are with the cricoid, must also undergo a separation from the recessed part of the thyroid, and the vocal cords must of necessity be lengthened and made more tense. Supposing this to have occurred, or even that the crico-thyroid muscles act chiefly in maintaining the thyroid cartilage fixed in regard to the cricoid, then the innermost bundles of the posterior crico-thyroid muscles, fig. 13, 1, will draw the arytenoid cartilages backwards, and so still further tighten and lengthen the vocal cords.

On the other hand, when the crico-thyroid and posterior crico-arytenoid muscles cease to act, the lateral crico-arytenoid muscles, 3, and especially the thyro-arytenoids, 4, will relax the vocal cords by drawing their anterior and posterior points of attachments to the thyroid and arytenoid cartilages respectively nearer to each other. The vocal cords at the same time, from having been stretched, become shorter by virtue of their elasticity.

As regards the narrowing of the glottis, it is, in the first place, obvious that the arytenoid muscle, 2, will draw the two arytenoid cartilages together, and so approximate the vocal cords, or even make all the parts touch each other, so as to close the glottis completely. But as the arytenoid cartilages are provided each with an anterior projection or process to which the corresponding vocal cord is attached, and an outward or lateral process to which the lateral and posterior crico-arytenoid muscles, 3 and 1, are inserted; and since, moreover, these little cartilages are so articulated upon the summit of the cricoid as not only to be able to be moved backwards and forwards and from side to side, but also to perform a movement of rotation upon their vertical axis,—that is, upon an imaginary line passing through them from above,—a movement much resembling that of a bell-crank as used in the corners of rooms,—it follows that the outer fibres of the posterior crico-arytenoid muscles, 1, can draw backwards the lateral processes of the arytenoid cartilages, swing the anterior processes outwards, and thus separate the vocal cords from each other behind, and widen the glottis, especially at its back part.

On the other hand, when the lateral crico-arytenoid muscles, 3, come into action, they must draw forwards the lateral processes of the arytenoids, and so swing the anterior processes inwards, approximate the vocal cords, bring them into a state of parallelism, and narrow the aperture of the glottis.

Many other most complicated actions of the laryngeal muscles have been noted by physiologists; and it is plain that the modes in which they, or their parts, may act in combination, must be very numerous. All such movements, whether sensori-motor, instinctive, emotional, or voluntary, are governed by the nervous system, and, when voluntary, as for the purposes of speech or vocalization, they are most nicely adjusted to produce results in accordance with the requirements of the presiding sense of hearing. The accuracy required in the condition of the vocal cords as to length and state of tension for the production of different sounds is truly marvellous; and to account for all the notes and intermediate tones possible in a perfect human voice of ordinary range, it has been calculated that 240 different conditions must be accurately producible at will; and, in one highly-gifted vocalist —the celebrated Madame Mara—as many as 2,000 changes could be faithfully effected when required. The human larynx, indeed, is the most wonderful vocal or musical apparatus within the scope of our observation, and it affords a striking example of the successful application of living tissue to delicate physical uses in the animal economy.

Voice in Animals and Speech in Man.

All air-breathing animals, and those only, are capable of emitting true voice, by means of the air escaping from the respiratory organs. The noise made by fishes when brought into the atmosphere is of a different and purely accidental kind, depending on the sucking or flapping movements of their mouths or their gill-coverings. One or two fishes, however, in which an air-bladder opens into the pharynx, may make a noise from the escape of the contents of that sac.

The simple, soft, slit-like glottis of the newts and most batrachia, produces at best only a little snapping or sucking sound; whilst the croaking of the male frog is due to vibrations produced in air passing rapidly from the lungs into and out of certain sacs developed in the floor of the mouth at each side of the tongue.

In the reptiles, the larynx being cartilaginous and firmer, and the glottis having more contractile margins, the sounds produced by them are either of a soft or a harsh hissing character.

In singing-birds the proper vocal apparatus is not in the larynx, but lower down at the bifurcation of the trachea. It is often very complicated, having its special cartilages and muscles. The sounds it emits are, in birds of song, most varied in tone and always beautifully modulated, but in other birds monotonous, and frequently very harsh. In some birds there is no tracheal vocal apparatus, and these have no proper song, but only certain calls or croaks, produced by the aid of the larynx itself.

In all mammalia, as in man, the larynx is the organ of such voice, or rather cries, as they can utter; but, as a rule, their powers of vocal expression, whether indicative of joy, rage, or fear, are exceedingly limited, and but seldom agreeable to the human ear.

Even man, during infancy, can only cry. By degrees, induced by an instinct or tendency to imitation, and guided by the sense of hearing, he involuntary learns to emit certain other and truly vocal sounds, or *voice;* the range of expression in which, equalling his feelings, wants, and capacities, is vastly beyond that of animals. By long cultivation, according to the innate power in different persons of appreciating the harmonies of sound, voice is modified, so as to produce graduated *musical tones*, which by being variously combined become *song;* whilst the power of moulding vocal sounds into *articulate*, that is to say, *jointed sounds*, as they pass out through the mouth or nose, into definite *speech*, is acquired by continued voluntary exercise and imitation. Finally, under the dictation of our wants, desires, and intelligence, speech assumes the forms of *language*.

It is interesting to study, in one's self, the ways in which vocal tones are converted into articulate sounds by the *organs of speech*, the palate, tongue, lips, and teeth.

Thus, the true *vowel* sounds, or *open* sounds, as they are called, are really uninterrupted vocal tones, modified by various positions of the tongue, and by the gradual prolongation of the cavity of the mouth by means of the lips, as we utter in succession the pure vowel sounds, *ā*, *ă*, *e*, *o*, *u*. The diphthong sounds, *i*, *ei*, *eu*, and the sounds of *y* and *w* at the beginning of words, are modifications of the vowel sounds produced by other and slight changes in the form of the mouth. The *consonants*, or *shut* sounds, require a shutting or valve-like action to take place, either between the lips, as in the case of *b*, *p*, and *m;* or between the upper teeth and lower lip, as *f* and *v;* or between the tongue and the palate, as *d*, *g* hard, *c* hard, *k*, *q*, *t*, *r*, *l*, and *n;* or are produced by hissing sounds between the tongue and teeth, as *c* soft, *s*, and *z;* or by combination of some of these actions, as in the compound articulate sounds of *j* or *g* soft, *ch* soft, *ch* guttural, *ph*, *sh*, *th*, *ng*, and *x*. Lastly, the aspirate *h* is produced by merely giving increased force to the breath.

The terms, *labial*, *palatal*, *nasal*, and *guttural*, applied to certain consonant sounds, as, for example, to *p*, *t*, *n*, and *ch* Gaelic, sufficiently attest the seats of their production. They are all, as well as the vowel sounds, the result of a nice adaptation of muscular forces to the requirements of the sense of hearing. Such consonants as can be uttered only after a complete stoppage of the breath at some point or other, either at the lips, as *b* and *p*, or at the front part of the palate, as *d* and *t*, or at the back of the palate, as *g* hard, and *c* hard, or *k*, are termed *explosive* consonants: in producing them, the opening leading from the pharynx to the nose is quite closed, and all the breath passes through the mouth. Another class of consonants is called *continuous*, because there is not a complete stoppage of the breath previous to their utterance,—such as *v*, *f*, *s*, and *z*, for which the air passes with a degree of friction through the mouth only, *m* and *n*, for which it passes through the nose only, and *l* and *r*, in which it escapes through both passages,—*l* requiring air to escape at the sides of the tongue, whilst *r* demands a vibratory movement of that organ.

Vowels, or vowels with consonants, form *syllables*, which again constitute *words*, or, as they are called, *parts of speech*. In one minute we can utter 180 words, or 300 syllables, each on an average requiring the combination of 3 articulate sounds; so that 900 changes in the movable organs of speech occur in that period; and these complex yet nice muscular mutations, 15 in a second, may be continued for several hours.

In describing the articulate sounds of language, we have necessarily illustrated the fact, that man has invented *signs* or *letters* to represent those sounds. By passing thus from the domain of the ear to that of the eye, and by using pictures, hieroglyphs, symbols, syllabic signs, and, lastly, a more or less perfect phonetic alphabet, founded on an analysis of the elementary sounds of speech, *oral* or *mouth* language (*os*, *oris*, the mouth) became concrete in *written* forms, and so led to the invention of *printing*, with all its momentous consequences.

However much languages may differ, nearly all their elementary sounds are alike, just as the organs of speech correspond in all men; though probably there are, in different cases, slight differences in these organs, original or acquired, which harmonize with the prevalence of certain sounds, the absence of others, and the more rare employment of special ones, in any given tongue.

Although speech, or the utterance of articulate sounds, is commonly associated with the production of voice, it is not necessarily dependent on it; for in the act of *whispering*, the articulation of the words is perfectly performed, but without any laryngeal action or vocalization,—as may be readily felt by any one who makes the experiment of first whispering and then speaking, watching all the while the sensations in the larynx, and noting by the hand or otherwise the absence or occurrence of vibrations in it. This distinction between vocalization and non-vocalization is also illustrated in the difference between a sigh and a groan, the latter being the former vocalized. Again, the sounds of the alphabet, except *c* soft or *s*, *g* soft or *j*, and *z*, may be articulated without voice, or with only an imperfect laryngeal action, by drawing *in* the breath, as is done by some persons at the end of their sentences. The peculiar *clicks* heard in some African languages are produced by bringing the tongue sharply out of contact with the hard or soft palate. A similar action of the tongue against the upper gums causes a sound, not expressed in writing, which, by repetition, indicates amongst ourselves a sort of petty vexation. This and the African clicks are mouth-sounds requiring no breath, much less voice. *Smacking* the tongue and lips, as an expression of relish, and *kissing*, are also of the same character. *Whistling*, however, is a mouth-sound dependent on breath, but not on voice. The sounds of *laughter* are truly vocal, being the aspirated vowel sounds *a*, *e*, or *o*, convulsively repeated.

Lisping, and *stammering* or *stuttering*, are generally due to errors in the action of the organs of speech, and not to structural defects. In most cases they may be remedied by patient and persevering practice, founded on an accurate perception of the erroneous movements and their correct substitutes. *Dumbness* is an affliction conjoint with deafness from birth,—the ear no longer serving as a guide for the purposes of articulation. In a few deaf mutes a sort of speech has been acquired by painful guesses at the proper sounds. There are mutes who are not deaf, the absence of speech being due either to defects in the mouth, or perhaps in some of the nervous centres concerned in the faculty of speech.

As the glottis is the aperture through which all respiration takes place, there are several functions which it performs in connection with the respiratory apparatus, besides that of producing voice. It is, indeed, the watchful guardian of the pulmonary organs. The sensibility of its mucous membrane, and of that of the superior opening of the larynx, derived from branches of the pneumo-gastric nerve, fig. 9, 8, is very acute, and all its muscles are placed under voluntary, emotional, sensori-motor, or reflex control by means of branches of the pneumo-gastric and spinal accessory nerves.

The sensibility of the glottis and the immediately overlying parts is so delicate that the slightest portion of any foreign substance accidentally entering them,—whether it be solid, liquid, vaporous, or gaseous, such as dust, cold water, mucus, or blood, the fumes of vinegar or of carbonic acid,—produces instant tickling; and there immediately ensues, by involuntary reflex action, either sudden and spasmodic closure of the glottis to prevent the introduction of the noxious substance, or else explosive efforts of coughing to get rid of it from passages organized specially for the conveyance merely of a bland atmosphere. Even air too cold or too dry will produce irritation and cough.

The closure of the glottis is effected chiefly by spasm of the arytenoid muscles, fig. 14, 2; but probably other muscles are somewhat concerned in it. In the act of coughing, the whole of the respiratory muscles are set in action, accompanied by alternate closure and opening of the glottis. In sneezing, also, the glottis is first closed, after a full inspiration, and then the air is driven through the nose, to expel any irritating agent from it. In hiccough, too, the glottis is spasmodically closed, immediately after a spasmodic reflex action of the diaphragm has taken place.

The glottis is sometimes momentarily closed by the action of its muscles, under the influence of emotion, as in laughter, or when the breath is caught in violent sobbing.

Lastly, these same muscles sometimes act under the influence of the will, so as forcibly to close the glottis, as when we voluntarily prepare to cough, or clear the throat by hemming; or, again, as when, after filling the lungs with air, we shut it in by tightly closing the glottis, and thus are enabled by the action of the muscles of expiration, to render the chest tense and its sides firm, preparatory to resisting pressure in diving or receiving the blows of an antagonist, or for making efforts, especially with the upper limbs, as in striking, lifting, pulling, or climbing. This action of the glottis has often been quoted as a remarkable instance of the successful resistance by a small force of a very much greater one; for in this action the little arytenoid muscles, which close the glottis, may be said to support an effort or pressure made against them by all the ordinary and accessory muscles of expiration. A pavior working in the streets affords an amusing illustration of this fact: the glottis having been closed and the chest rendered firm to enable him to effect the necessary elevation of his ponderous rammer, a curious short grunt, which accompanies its descent, shows that the glottis is once more opened and the pent-up air liberated from his collapsing thorax. To make a good shot with a rifle, it is necessary to take aim from a well-filled chest, and with the breath held tight.

No. 8.—The Organs of the Senses.

THE Organs of the Senses, to the illustration of which this diagram is devoted, are those of *Touch*, *Taste*, *Smell*, *Hearing*, and *Sight*.

Figs. 1 to 9 relate to the Skin and its Appendages,—figs. 1 to 4 being magnified plans of the structure of the Skin, figs. 5 and 6 of the Nails, and figs. 7 to 9 of the Hairs and Hair-follicles.

Fig. 10 is an enlarged view of the upper surface of the Tongue, showing the eminences upon it called the papillæ, magnified plans of which are represented in fig. 11.

Figs. 12 to 14 illustrate the structure of the organ of Smell,—fig. 12 being a vertical section made a little to the right of the middle line of the nose, fig. 13 being a transverse vertical section across the nasal cavities and the roof of the mouth, and fig. 14 showing the cartilages of the nose.

Figs. 15 to 19 exhibit the mechanism of the superficial and deep-seated parts of the organ of Hearing. Fig. 15 is a sectional plan, designed to show these various parts in their relative order and connection, though, owing to the difficulty of so representing them in one view, not exactly in their real positions. Figs. 16 to 19 are enlarged representations of some of the more important deep-seated parts.

Figs. 20 to 25 are devoted to illustrating the structure of the Eye and its Appendages. Their numerous details will be described with that organ.

The objects represented in this diagram being for the most part familiar, it will be readily seen how much they are enlarged; but in the case of the microscopic delineations, such as figs. 1 to 9, and fig. 11, the degree of enlargement will be stated hereafter. The colours employed are more or less conventionalized, though adapted from nature.

The Organs of the Senses in General.

The essential conditions necessary to sensation, as already explained under diagram No. 7, p. 113, are the existence of sensory afferent white nerve-fibres in connection with a sensorium or central mass of grey nervous matter, and the presence of some stimulus capable of acting upon them. Hence some of the lowest animal organisms, which are entirely destitute of a nervous system, are believed by most physiologists to be destitute of sensibility. Nevertheless, speaking generally, to *feel*, after some fashion or other, is manifestly one of the characteristics of animal life.

The simplest, but at the same time the most widely diffused, form of sensation is that which depends on what is termed *common sensibility*. All but a few of the lowest animals possess it, and nearly all the tissues of the highest animals and man,—for we must except those which, like the scarf-skin or cuticle raised by blistering, the tegumentary appendages, scales, hairs, nails, and horns, the teeth, the clear parts of the eye, and the cartilages of the joints, are destitute of nerves. Those tissues which do possess it, have it in different degrees, according to the number of sensory nerves with which they are provided. Thus bones and tendons contain very few nerves; ligaments, fasciæ, cellular membranes, serous and synovial membranes, rather more; muscles still more; mucous membranes, especially at the parts continuous with the skin, have many more; and, lastly, the skin itself most of all. The relative sensibility of these parts increases in the very same order.

By means of this generally diffused common sensibility, or modifications of it suited to particular purposes, animals as well as ourselves experience all kinds of *internal* sensations,—such as inward changes of temperature, comfort or pain, ease or disease, hunger, thirst, nausea, a general sense, probably connected with the state of the blood and capillary circulation, of lightness or exhilaration, a sense of depression, the feelings of sinking, weight at the pit of the stomach, oppression at the chest, palpitation of the heart, and other common sensations of an agreeable or disagreeable kind. A particular modification of this internal common sensibility, or, as some have considered it, a distinct, additional, or *sixth sense*, is that which is called the *muscular sense*, by which we are informed of the state of the muscles, their amount and force of contraction, and their condition as to vigour or exhaustion, and to which, together with a sense of resistance at the joints, we owe the power of appreciating resistance and weight, and indirectly the particular command over the different muscles and the general balancing power over the whole muscular system. By this internal sense of the state of the muscles, we also appreciate in part the delights of physical exercise, and the distress of fatigue, cramp, spasm, and also the choking sensations experienced from certain painful emotions. On the *surface* of the body, *i. e.* in the skin, and also in its extensions into the interior, as at the eyelids, nose, ears, and mouth, the common sensibility is still more perfect than in the deep-seated parts and tissues. It is the source of all sensations of cutaneous pain or pleasure, of the surface-feeling of heat and cold, and of that general sense of mere contact with things material, which informs us of the presence of external objects. In all these ways, therefore, this common sensibility, in its various modifications, not only enables us subjectively to become conscious of the existence of our own bodies, but is sufficient to inform us objectively of the existence of a world around us.

It is necessary, however, for the higher animals, and especially for us, to be able to appreciate still more exactly the physical properties of matter, changes of temperature, taste and odours, sounds and light. For this end, we, in common with the higher animals, are gifted with special sensibilities, or *special senses*, dependent on the existence of *special sensorial centres* in the nervous system, *special nerves* to convey the *special* impressions to them, and *special apparatuses* placed at the extremities of those nerves, at once protective and adaptive, by which the impressions characteristic of each sense are received upon those nerves without pain and in some specially devised manner. These apparatuses are the *organs of the senses;* viz., the skin, especially of the hands, as the organ of touch, the tongue and palate as the organs of taste, the nasal cavities as the organs of smell, the ears as the organs of hearing, and the eyes as the organs of sight.

THE ORGAN OF TOUCH.

THE SKIN WITH ITS APPENDAGES, THE NAILS AND HAIRS.

The Skin.

Figures 1 to 4.

THE human skin, that frontier fence and utmost living verge of the body, at once limits, protects, and adorns the human frame, and connects it, by its sentinel-like sensibility, with the outer world.

Besides this, whilst under certain circumstances it absorbs fluids from without, it contains a grand exhaling apparatus for the escape of redundant moisture, and the throwing off effete matters from the system.

To fulfil these various conditions, it is strong and tough, and at the same time supple, elastic, and flexible, especially around the joints. It has a soft and agreeable texture, and a singular beauty of colour. Whilst it conceals the disagreeable anatomical details of the subjacent parts, it reveals, owing to its comparative nakedness, their remarkable beauties of form. It is provided with countless nerves; it is warmed and nourished by myriads of capillary vessels; and, its superficial layers, together with the nails and hairs, being continually shed and regenerated from birth to death, it is, though changed and worn, preserved under proper care in uninterrupted purity and health. Lastly, it contains numerous absorbent vessels, and millions of little glands, which secrete the sweat, and a certain fatty matter which anoints the whole surface.

At the eyelids, ears, nose, and mouth, the skin is conterminous with the mucous membranes of those parts. In the neighbourhood of these apertures, indeed, those membranes partake more or less of the characters and functions of the skin, and hence, viewed generally, may be said to form the internal skin, or inverted surface of the body. In this sense, bread undergoing digestion in the stomach is as much outside the living organism, as a crust still held in the hand.

The skin is thicker on the back than the front of the body, thicker on the outer than the inner surfaces of the limbs, thicker still in the palms of the hands, but thickest of all in the soles of the feet. It is very thin on the eyelids, in the tube of the ear, and on the red borders of the lips, where it gradually changes into mucous membrane.

Besides the evident foldings at the joints and the wrinkles of old age, the skin is nearly everywhere marked with fine intersecting lines or furrows, which divide the surface into minute angular spaces. On the soles of the feet and palms of the hands, and especially on the toes and fingers, it is elevated into little ridges, usually parallel to one another, and sweeping over the surface in curved lines.

Fig. 1, representing a piece of the end of the thumb, magnified about thirty-two diameters, shows these ridges, which correspond with rows of the concealed eminences called papillæ, and on which, in the middle of certain slight depressions, are seen the mouths of the ducts of the sweat-glands. By the aid of a watchmaker's lens, all the parts shown in fig. 1 can be plainly seen; and if the hand be hot and perspiring, minute shining specks of moisture will appear oozing from the mouths of the sweat-ducts, and more or less rapidly evaporating away. In other parts of the skin, the openings of the sweat-glands are scattered irregularly about, and where hairs exist, these are seen to project from special little depressions, which are the orifices of the hair-follicles.

The skin consists of two closely-adherent though separable layers, one external, or superficial, non-vascular and insensible, for it is entirely destitute of vessels and nerves, named the *Cuticle*, or *scarf-skin;* the other deeper, internal, highly vascular, abundantly supplied with nerves, and therefore highly sensitive, called the *Cutis*, or *skin proper*.

a. The *Cuticle*, called also the *Epidermis* (επι *upon*, and δερμα, the *skin*), is that part which is raised from the cutis in the form of blebs or blisters in certain skin diseases, and from the effects of burns, scalds, or the application of blistering fluids or ointments. In these cases, a serous fluid exudes through the coats of the capillaries of the inflamed vascular cutis, between the surface of this and the non-vascular cuticle, and so the latter is raised up in the manner well known. As a result of decomposition after death, the cuticle easily separates from the cutis. When thus loosened, and slowly lifted up, it is seen to be accurately moulded to the surface of the cutis, closely following all the flexures, markings, and ridges of the skin, which are really formed in the cutis and only copied by the cuticle. The cuticle is also observed to penetrate, or prolong itself into the ducts of the sweat-glands and hair-follicles, which lie bedded in or beneath the former.

Fig. 2, magnified 130 diameters, is a perpendicular section through a piece of the skin of the palm, corresponding to one and two halves of the parallel ridges represented in fig. 1. The cuticle marked *a*, *b*, adheres closely to the surface of the cutis *c; p* marks the papillæ of the skin, consisting of minute prolongations of the cutis, here placed on the ridges, and jutting into the cuticle; *d* is a sweat-gland, situated just beneath the cutis; *e* is the duct of this gland, which, after a spiral course through the cuticle, opens on the middle of one of the cutaneous ridges; *f* indicates little collections of fat in the oreolar tissue beneath the skin.

Where the entire skin is very thin, the cuticle itself is not more than $\frac{1}{240}$th inch in thickness; but in the palms of the hands and soles of the feet, where it is thickest, it measures as much as $\frac{1}{12}$th of an inch. It grows thicker in the palms and soles, from the effects of hard work and pressure, as seen in the hands of operatives, boatmen, and cricketers, and in the feet of bare-footed pedestrians.

The cuticle also constitutes the substance of corns, which are produced by too loose or over-tight boots or shoes, or by those absurd but fashionable high-heeled cages, into which the feet are so painfully driven forward in walking.

The greater thickness of the skin of the hands and feet has been attributed, by those who regard the peculiar adaptations of the parts of organized beings to particular ends as the result of external influences only, to the effects of pressure or friction; but in this case, any such explanation is completely untrue; for the skin of these parts is already thicker in the new-born infant, in accordance, unquestionably, with intentional providential design. The same may be said of the flexures of the skin at the knuckles, on the inner aspect of the hands and fingers, and elsewhere; for these are not produced by the action of the muscles, but are formed designedly, in correspondence with them, to facilitate the movements of the parts.

The superficial portion of the cuticle, marked *a* in figs. 2 to 6, is dry, firm, and nearly transparent, whilst its deeper parts, marked *b*, are moist, softer, and more opaque. These are not, however, two distinct layers, but only portions of the same structure, in different stages of formation. When macerated and examined microscopically, both parts are found to consist of nucleated cells, arranged in superimposed layers, as shown in fig. 4. The deepest of these cells, resting on the cutis, are soft, roundish, or compressed, and easily separated from each other; whilst those above them are more and more flattened, drier, and more firmly held together, until quite at the surface they are arranged in myriads, as thin coherent microscopic horny scales (see diagram No. 9, fig. 77). During life, these scales are constantly being rubbed or washed off; and to supply this loss by desquamation, fresh nucleated cells are continually being generated on the surface of the cutis, in the nutrient material poured out by its blood-vessels, and these in turn, undergoing the necessary changes in shape, consistence, and even chemical constitution, in time reach the surface of the body, and finally are themselves loosened and thrown off.

This process, by which the cuticle, though ever wearing, is constantly renewed, presents an intelligible example of *continued growth, i. e.*, of the persistence during the whole of life of a growth which began in the early period of development. In the thickening of the cuticle, which results from pressure or friction, new cells are generated faster than the old ones are thrown off; and this apparently owing to excitement of the subjacent vascular cutis, causing it to pour out on its surface an unusual quantity of the nutrient material in which the new cells arise, thus affording a good illustration of the adaptive powers of animal organization.

The deep softer part of the cuticle was named by Malpighi the *rete mucosum*, or *mucous network;* and as this part is very dark in the Negro's skin, the colour of which is mainly owing to it, it was at one time regarded as something peculiar to the dark races, and as not existing in the white. But the structure of the skin, and mode of growth of the cuticle, are essentially the same in all the races of mankind; the same soft layer being found in the white skin as in the black and coloured skin, but being of a pinkish, instead of a black or dull hue. In the dark races, the colour is owing to the presence of animal *pigment*, chiefly in the form of coloured molecules, situated in the nucleated cells, or in proper pigmentary cells, as shown at *b*, fig. 4, which represents these cells as seen in the deeper parts of the cuticle of the Negro. As the cells approach the surface, the pigment molecules become less evident, and the most superficial scales are still paler; so that the colour is mainly due to the deep layers of cells, and, at any rate, is entirely confined to the cuticle; for the vascular cutis or true skin in the Negro has the same hue as in the lighter-coloured races.

The use of the horny, insensible, and quickly-regenerated cuticle, is evidently to protect the vascular and nervous cutis, which is exquisitely sensitive when exposed, as after a blister, burn, or scald. The cuticle also resists the entrance of poisonous or noxious substances into the body through the cutaneous surface; for most of these can be handled with impunity when the cuticle is entire, though they would be rapidly absorbed by the exposed surface of the cutis. A small amount of water, oil, and many other substances, nevertheless, may penetrate the cuticle; as is proved by persons, deprived of fresh water at sea, being able to slake their thirst by bathing or wetting the clothes they have on in salt water; also by the fact, that cod-liver oil, narcotics, and other remedies, may be introduced into the system *endermically*, as it is called, that is, by rubbing into the skin; and also by the effects of blisters and mustard poultices, which really act through the cuticle upon the cutis. Absorption through the latter is very active, and often dangerously so.

Lastly, the cuticle prevents a general evaporation from going on, practically restricting the loss of fluid from the surface of the body to that secreted by the sweat-glands.

b. The *cutis* or *true skin*, also called the *Corium* and *Derma*, is a dense, pinkish-white, moist, tough, and flexible membrane, everywhere covered by the cuticle or epidermis, and adherent to the subjacent parts,—usually to the subcutaneous cellular and fatty tissue, sometimes to the fascia, as in the palms and soles, or, again, as in the face, to the underlying muscles.

On its surface, next to the soft layer of the cuticle, it is compact, scarcely fibrillated, almost homogeneous in its texture; but deeper in, it is fibrous, being built up of close interlacing bundles of dense white areolar tissue, mixed with yellow elastic fibres, and in most places, and always where hairs exist, with scattered contractile or unstriped muscular fibres. Still deeper, the fibrous network becomes looser, and, opening out, incloses the hair-follicles, fig. 7, *s*, with their sebaceous glands, *g*, the sweat-glands, fig. 2, *d*, and little masses of fat, *f*, and finally passes into the loose areolar and fatty tissue beneath. Over the angles of the joints, the skin is very loosely attached, and there are often little closed spaces or *bursæ*, as they are called, between the skin and the prominences of the bones, which facilitate the movements of the one over the other. In the palms and soles, where a looseness of the cutis would have been inconsistent with its functions, it is very firmly adherent to the fascia beneath; and in the face it receives on its under-surface many of the muscular fibres of the eyebrows and mouth, which act upon it in producing the various expressions.

In the densest part of the sole, the cutis is a line and a half thick, and, as the other extreme, in the eyelids it is less than a quarter of a line. It is the cutis which determines the thickness of the entire skin, except in the palms and soles, where the cuticle is disproportionately thick.

The surface of the cutis is more or less closely covered with a multitude of the little projections called *papillæ*, figs. 2, 3, and 4, *p*, which are really prolongations of its upper compact tissue into the deep soft part of the cuticle covering it.

Fig. 3, *p*, magnified 350 diameters, shows their characters in the skin of the palm, where they are largest and most numerous. Arranged usually in double rows, fig. 2, upon the cutaneous ridges, they are bluntly conical processes, usually divided so as to form *compound* papillæ, and measuring from $\frac{1}{200}$th to $\frac{1}{100}$th of an inch in length. In the soles they are nearly as large; but in other situations they are shorter, smaller, and more scattered, measuring from $\frac{1}{500}$th to $\frac{1}{1500}$th of an inch in length, and in some places becoming indistinct or disappearing altogether.

The cutis is highly vascular, as is proved by the free bleeding when the skin is just pricked or scratched. Commencing in arteries and ending in veins connected with the larger subcutaneous blood-vessels, the capillaries of the cutis supply the hair-follicles and sweat-glands, and form a close network over the general surface, from which fine looped vessels enter the papillæ, varying in number according to the size of those processes. See fig. 4, *v*, and also diagram No. 9, fig. 61.

The lymphatics or absorbents of the cutis are very abundant, and form a close network on the surface. The cutis is abundantly supplied with sensory nerves, which are most numerous where the papillæ abound. Entering the cutis from the subcutaneous cellular tissue, they form, as they approach the surface, fine plexuses, from which branches, composed of only a few nerve-fibres or even of a single fibre, are given off. Some of these fibres divide, and so become lost in the upper compact layer of the cutis; others perhaps end in loops; whilst, finally, great numbers pass into certain of the papillæ—not into all—and there end either in loops, or else, as shown at fig. 4, *n*, upon little oval bodies, called *tactile corpuscles*, which occupy the centre of the papillæ, or are lost in the homogeneous central part of such papillæ as do not appear to possess distinct tactile corpuscles.

In the hands and feet, and in a few other positions, some of the cutaneous nerve-fibres pass into curious little bodies called the *Pacinian corpuscles*, which consist of numerous superimposed concentric membranous laminæ, having intervening spaces, and a central chamber into which the axial part of the nerve-fibre penetrates. They are found in great numbers in the feet and elsewhere in many animals, and especially on the nerves in the mesentery of the cat. Their use is not certainly known. They may be a sort of highly-developed tactile corpuscle, a view which is supported by the fact that little bodies presenting an intermediate kind of structure have recently been found at the extremities of the nerves in the mucous membrane lining the human eyelids; and, it may be added, in different parts of animals. It has also been conjectured by many, that they may have some electrical use, and be related to the simpler forms of electric organs found in certain fishes.

The cutaneous papillæ, which constitute the most characteristic feature in the anatomy of the cutis, are, in the first place, vascular organs, which serve to increase the nutrient and formative surface for the generation of the constantly wasting cuticle. Those which contain nerves are, however, the proper organs of *tactile sensibility* or *touch*, and their number, size, and complex development are in exact proportion to the perfection of this sense in different parts of the skin.

It has been shown by experiment, that the thick skin of the back is less sensitive than the thinner and more delicate skin of the front of the body; the outside of the limbs is less so than the inside, and the parts of the limbs nearer to the trunk less so than those more remote, especially the feet and hands. In the face, the sensibility increases successively in passing from the forehead to the cheeks, eyelids, and white part of the lips, and is most acute in the red borders of the latter. The soles of the feet are less sensitive than the hands. The tips of the fingers and thumb, but especially the outer side of the end of the forefinger, present the tactile sense of the skin in the highest degree of perfection. The tip of the tongue, with its thin delicate mucous membrane and numerous nervous papillæ, is even more sensitive than the skin. The tube of the ear, the mucous membrane of the eyelids, the white part of the eyeball, the lining membrane of the nose, and the margins of the glottis, are also highly sensitive, principally to warn us, in their respective regions, of the presence of foreign and noxious bodies.

In reference to the hand (as already indicated at pp. 11, 18, 22), its incessantly-employed uses as an organ of touch, in recognizing not mere materiality, but the varieties of consistence, surface, and form, and in exercising all kinds of manipulations, depend not only on the number, size, structure, and nervous supply of its papillæ, but also on the wonderful adaptation of the entire mechanism of the upper limb, its bones, joints, and muscles, for the due fulfilment of the tactile and prehensile functions of its digital extremities.

The Nails.

Figures 5 to 6.

The *Nails* are modified parts of the cuticle, occupying its place, and so continuous with it, that when the hand or foot is sufficiently decomposed, they slip off from the true skin, in intimate connection with the glove-like cuticular sheath.

In figs. 5 and 6, which are transverse and longitudinal sections through the nail, is shown the way in which these defensive organs, *n*, resting immediately upon the cutis or true skin, *c*, are continuous with the cuticle *a b*, along the hinder half of their edges, by their upper surface near the root, and by their under surface near the tip.

The part of the cutis *c* on which the nail rests, to which during life it firmly adheres, and on which it is fashioned as on a mould or bed, is called the *matrix*. At its hinder part, this is doubled on itself, so as to form a semilunar groove, or recess, into which the root, or posterior edge, of the nail is closely set. This matrix is highly vascular, and, excepting opposite the crescentic white spot seen near the root of the nail, called the *lunula* (the young moon), is elevated into vertical ridges, running lengthwise under the nail, and covered (as shown in the transverse section, fig. 5) with rows of vascular papillæ, which serve to fix and nourish the non-vascular cuticular covering or nail.

The substance of the nails consists of a deep soft layer, resting on and between the ridges of the papillæ of the matrix, and of a hard superficial stratum,—the two corresponding with, and being traceable into, the soft and hard layers, *b*, *a*, of the cuticle itself. The soft stratum is composed of roundish somewhat compressed nucleated cells, which gradually change into flattened horny and intimately-adherent cells at the surface. Like the cuticle, the nails are constantly being reproduced, growing in length by continual additions of new cells to their posterior margin, and in thickness by little additions to their under surface. When a nail is torn out, or thrown off in consequence of disease, its matrix being uninjured, a perfect new nail is formed by the successive production and modification of nucleated cells upon the exposed vascular surface; but if the matrix be partially destroyed, or altered in shape, the new nail reflects the deficiency or deformity, being only a copy of the surviving matrix itself.

The human nails, with their fine breadth, as compared with the narrow nails or flat-sided claws of animals, constitute a beautiful finish and ornament to the hands and feet. They also support and steady the pulps of the fingers in the manifold uses of these parts; and there are almost hundreds of little mechanical acts, such as the solacing scratch, the fastening of buttons, the management of the pin, the untying of knots, the manipulations of various artificers, and even certain nice surgical proceedings, in which no substitute for the nail can be found.

The Hairs.

Figures 7, 8, and 9.

Hairs of large or minute size exist on all parts of the body, excepting the palms of the hands, the soles of the feet, the backs of the last phalanges of the fingers and toes, and the surface of the upper eyelid. Their general arrangement is very constant; and whether they form the fine down seen on the bodies of infants and the faces of youths, the silken eyelashes, the short stiff hairs of the eyebrows, the longer and stouter beard, or the strong flowing hair of the head, with its different characters in the male and female and in the different races of mankind,—they are, like the nails, non-vascular and insensible outgrowths of the cuticle, springing from a minute sunken point of the surface of the true skin, which has no other cuticular covering at that point.

When examined closely, the depression from which a hair emerges is seen to form a little sac, or follicle, buried in the true skin, or, as in the case of the larger hairs, reaching even beneath it as deep as the subcutaneous fat. With the exception of the eyelashes, which are set perpendicularly to the surface, the hairs are usually inserted obliquely into the skin.

Fig. 7 is a longitudinal section of a hair-follicle, magnified 150 diameters. The sides of such a follicle, *s*, formed by fibrous and membranous layers derived from the cutis, *c*, are lined by extensions of the soft and horny layers, *b*, *a*, of the cuticle. The bottom of the follicle consists of a more or less elevated portion of the vascular cutis, often of a distinct eminence or papilla, *p*, which is destitute of cuticle, but is covered instead by the attached extremity of the hair, *h*. The hair, indeed, is formed on this papilla, by the gradual production and special metamorphosis of a succession of nucleated cells, like the nails and the cuticle itself. Opening into the hair-follicles, in nearly all cases, are the sebaceous or fat-forming glands.

Fig. 8, magnified 600 diameters, shows the soft swollen end, *root*, or *bulb* of a hair, situated in its follicle or sac, *s*, and resting on its papilla, *p*, which is supplied from beneath by blood-vessels, *v*. At the root, the component nucleated cells are soft, pale in colour, and merely somewhat compressed. Along the stem of the hair, up to its very point, the outer cells become changed into imbricated and adherent scales, the edges of which directed towards the point, form fine wavy transverse lines; whilst the inner cells, assuming a fusiform shape, are clustered into flattened fibres, which run longitudinally, and constitute the bulk of the hair substance. This contains pigment-cells and granules varying according to its colour, and also presents little cavities filled with air. In certain hairs, the very deepest cells, for a certain distance from the papilla, are not elongated into fibres, but retain their loose aggregation and compressed form, and so form a sort of *pith*, or *medulla*, whilst the outer fibrous and firmer part is named the *cortex*, a term more strictly applicable to the imbricated scaly layer on the very surface.

Fig. 9 is a cross section of a large hair, showing the central pith, which is absent in fine hairs, and is only occasionally seen in the hairs of the head. It is very distinct in the hairs of certain of the mammalia, which, it may here be stated, present great variety of external contour, and form highly interesting microscopic objects.

Not only do hairs grow by additions of new cells to their root, but these cells must undergo alterations for some distance at least along the stem, which so becomes narrower than the bulb itself. The softer central portion, whether deserving the name of a pith or not, though of course non-vascular, is probably permeable to nutrient fluids, which nourish the hair, and to certain changes in which, produced through the blood, it is thought that the sudden whitening of the hair from grief, fear, or intense mental excitement is due. In the disease called *plica Polonica*, common in Poland and Hungary, the hair is inextricably matted together, and a viscid fluid actually exudes from the cut ends of the hairs; and if these are divided close to the scalp, blood issues from them, the vascular papillæ being apparently prolonged out of the hair-follicles above the surface of the skin.

When a hair is forcibly plucked out, the cuticular lining of its follicle comes away also, clinging closely around the root or bulb; but the vascular papilla at the bottom of the follicle remains, and a new hair is generated upon it. If, however, the papilla itself be destroyed by disease or injury, no new hair is formed. Hairs are often shed naturally, others being reproduced from the same follicles, as in the case of the hairs of new-born infants, of the eyelashes throughout life, and of the hair of the head at particular seasons. This phenomenon is more particularly marked in animals, and after the occurrence of erysipelas, fevers, and other illnesses. In some of these cases the new hairs grow from the old papillæ, beneath or so close to the falling hair, as to help in detaching it or thrusting it off; and in others the old hairs fall from want of nutrition before the new ones are commenced. When hairs are cut regularly, as in shaving or haircutting, it is said that they grow faster in length and thicker than if left alone; but if this be so always, it is to a limited extent only. The end of cut hairs often split, which is injurious, as the splitting may extend; but they may in time, either by simply wearing away, or by some actual process of modelling, or by both methods, re-acquire a point again.

In the description of the cutis, it has been stated that wherever hairs exist, muscular fibres of the smooth or unstriped variety are found in its substance. Many of these pass obliquely down from the surface of the cutis to the underside of the slanting hair-follicles. Hence, when they contract, as they will under the influence of cold or electricity, they erect the hairs, draw the follicles to the surface, and pull in a little point of the skin, producing that roughness of the integument which is called *goose's skin*, or *cutis anserina*. The standing on end of the hair of the head, as the result of excessive fright, may be partly due to a most exaggerated action of this kind, but must also be dependent on the contraction of the occipito-frontalis muscle, which is of course under the influence of the emotions. Hairs themselves are destitute of nerves; but the papillæ situated at the roots of the large whiskers of the cat, seal, and other animals, which are used as feelers, are supplied with very large nerves; and probably also nerves enter the papillæ of all but the finest hairs on the human body; for all are painful when pulled at or plucked out. Hence, the hairs, though perfectly insensible themselves, are wonderfully delicate instruments for the conveyance of the slightest impressions of touch, or even of the impulse of air, to the sensitive cutis in which they are implanted, warning us of the contact of insects, and of the presence of other bodies on the skin generally, and in regard to the entrances into the passage of the ear or nose, acting not only as mechanical but as indirectly sensitive guardians also.

In the same twofold manner, the eyelashes fringing the quickly-moving lids, protect the eyeballs; whilst the hairs of the eyebrows, acting in another way, moderate the access of light from above.

From the remarkable non-conducting property of hair for heat, it serves, in the beard of the male, as a protection against extremes of cold and heat, guarding, more perfectly than would a veil, the face against the latter, and, like a natural comforter and respirator, preserving the throat and air-passages from the effects of the former. Its main use, however, in both sexes, as a non-conductor of heat, is to protect the head and its important contents, the brain, from undue changes of temperature.

The ornamental character of the hair requires but a passing notice. It serves as a distinction between the sexes, and even between individuals; and it presents extraordinary differences amongst the races of mankind, varying in colour from the fairest blonde to the deepest black, and presenting many modifications in character; being either long or short, straight or crisp, curled or spiral, stiff, lank, silky, woolly, tufted, or matted altogether.

The chemical composition of the cutaneous tissues is of considerable interest. The cutis consisting chiefly of fibro-cellular tissue, is converted almost entirely into *gelatin* by boiling. It is this which enables the true skin of animals, cleared from its cuticle, to be made into leather by the action of tannic acid, as takes place in the process of tanning. The human cutis has also been preserved in this way. The cuticle and the nails, on the other hand, chiefly consist of an animal principle called *keratin*, which is also found in hairs, horns, hoofs, claws, and beaks, all of which are cuticular appendages. These parts also contain a little fat, they are easily softened in water, soon yield the keratin by boiling, and leave a small residue of earthy and metallic salts. The deep or soft layer of the cuticle differs chemically from the superficial horny layer,—yielding less keratin, and a little gelatin. The nails and cuticle are not very durable: hair, on the contrary, is remarkably indestructible, lasting for centuries in dry tombs, and being only less durable than the teeth and bones. As compared with the cuticle or nails, it is more densely organized, it is not softened in cold water, nor even in water at the ordinary boiling-point, but requires water at a high temperature under pressure before it yields. Moreover, its keratin is combined with a larger amount of ash, consisting of lime, iron, and other bases; and, lastly, it is impregnated more thoroughly with preservative and fatty substances. The very colour of the hair is sometimes preserved. Even the fine downy hairs of the general surface have been found in the fragments of skin of ancient marauders, taken from beneath the heads of nails by which it had been fixed to church doors.

The Glands of the Skin.

There are two kinds of glands found in the skin, viz., the sebaceous and the sudoriferous glands:—

a. The *sebaceous* or *fat-forming glands*, from *sebum* fat, exist in great numbers associated with the hairs. They nearly always open into the hair-follicles, either singly, or in pairs, which, as shown in fig. 7, is the more common arrangement, or even in larger numbers to one follicle. Each gland is a flask-shaped body, composed of from five to twenty little sacs clustered round and opening into a common duct, which communicates with the hair-follicle. The gland is lined throughout by a fine epithelium, and its unctuous secretion, formed by the agency of nucleated cells, first anoints the hair-bulb, and then oozes out upon the stem and the neighbouring surface of the cuticle, which it prevents from getting dry and cracked.

The sebaceous glands, the proper appendages of hair-follicles, are not found where, as in the palms and soles, no hairs exist. They are of considerable size on the face, especially on the nose, where, often becoming obstructed, their locked-up contents may be squeezed out like a sort of cast, which is vulgarly, but erroneously, called a maggot. There is, however, a particular parasitic worm named Acarus folliculorum, which in some persons infests these glands, especially when they are over-filled; and it is even supposed that these small epizoa consume the superabundant secretion. The sebaceous glands are very active in the natives of hot climates, especially in the Negro, the skin requiring, in such circumstances, additional protection against the effect of the sun's rays.

b. The *sudoriparous*, *sudoriferous* (from *sudor*, sweat, and *paro*, to prepare, or *fero*, to bear), or *sweat glands*, exist, in larger or smaller numbers, in all parts of the skin. They appear like little rounded bodies, averaging about one-sixth of a line in diameter, lying immediately beneath the true skin. Each consists of a slender tube, closed at its deeper end, and coiled up into a little ball, fig. 2, *d*, from which a straight portion of the tube, *e*, runs up through the cutis, *c*, and being continued in a spiral or corkscrew form through the cuticle, *ab*, opens out on the surface, as the excretory duct of the little gland. Sometimes two coiled tubes unite into one duct. When unrolled, the entire tube usually measures about a quarter of an inch long, and about $\frac{1}{300}$th inch in diameter. It consists of an outer vascular coat prolonged from the cutis, and an inner epithelial coat continuous with the cuticle. The spiral part consists of the latter only, and is usually drawn out with the loosened cuticle, after blistering or maceration of the skin; it is then, of course, reproduced; but the gland itself cannot be restored, if once destroyed.

In the palms and soles, the openings of the sweat-ducts, or the *pores* of the skin, are found upon the papillary ridges, as shown in figs. 1 and 2; in other situations they are scattered about the surface. Their total number is well-nigh incredible. In the palm there are 2,800 in a superficial square inch: they diminish in numbers successively in the sole, on the back of the hand, the forehead, and the front of the neck, trunk, and arms, where they are about 1,000 in the square inch; they are still fewer on the lower limbs, and fewest of all on the back of the neck and trunk, where they number from 600 to 400 in the same space. Supposing an average of 1,000 in a square inch, and estimating the entire surface of the body in an adult at 2,500 square inches, the total number of sweat-glands would be two and a half millions, each with its little mouth, or pore, for the escape of perspiration. The importance of the skin as an excreting organ is hence very evident.

The perspiration is a sour watery fluid, holding in solution or suspension not more than 1½ per cent. of solid substances, which consist of saline matters, lactic, and perhaps other acids, traces of urea, which is so abundantly excreted by the kidneys, and the epithelium of the sweat-glands.

The quantity of perspiration exhaled in a given time, depends mainly on the relative temperature and dryness of the air. At high temperatures, the general circulation being quickened, and the vessels of the skin and especially the capillaries of the sweat-glands receiving more blood, more perspiratory fluid is excreted; whilst by exposure to cold, which produces a contrary effect on the general and cutaneous vascular system, the perspiration is diminished. In this way, through the effects of more or less evaporation, a regulating influence is maintained over the temperature of the body,—its heat being lowered in the former case, and economized in the latter. In a very hot atmosphere fully charged with vapour, as in a vapour-bath, the cutaneous exhalation continues to be secreted, but it no longer passes off by evaporation, and the regulating influence is lost. Hence, heat is not so well borne under such conditions. The cutaneous exhalation necessarily moderates the temperature of the body in violent exercise.

Besides exercising this important physical influence, the perspiration, if the skin be kept clean and in a state of healthy activity, steadily relieves the blood of effete, impure, and therefore noxious matters. Supposing 20 oz. of perspiration to be exhaled daily from an adult, the quantity of solid impurities, at even 1½ per cent., would only be 130 grains: but the *quality* of these excreta is highly injurious; their supposed excretion, as in the act of catching cold, is often followed by serious consequences; and they are doubtless much modified under conditions demanding great efforts at purification of the blood.

In certain parts of the body, the sweat-glands are comparatively large. In the armpits, where they are largest, measuring nearly two lines in diameter, they are composed of branched tubes, and their secretion is thick and very acrid and odorous, contains pale yellowish granules, nuclei, and epithelium, and has a peculiar chemical composition. They must, therefore, act more powerfully as emunctories. It must likewise be evident that the sebaceous glands not only supply a lubricating fat for the skin and hairs, but also act as eliminating organs.

The necessity for constant ablutions of the entire skin,—not merely of the parts ordinarily exposed,—the rationale of baths, and the maxims embodying the high import of cleanliness, may all be deduced from the preceding account of its structure and functions.

THE ORGAN OF TASTE.

THE TONGUE.

Figures 10, 11.

The *Tongue*, besides being used in eating, swallowing, and speaking, is the part especially concerned in tasting, and is therefore correctly called the *Organ of Taste;* but this definition requires to be qualified by the statement that other parts of the mouth, especially the under-surface of the *soft palate* and anterior pillars of the fauces, are also endowed with the power of receiving impressions from bodies possessing flavour, or, as they are called, *sapid* bodies.

The mucous membrane covering the portions of the soft palate and fauces just mentioned, is supplied by branches of the superior maxillary division of the fifth cranial nerve (see fig. 12, 5), and also by branches from the glosso-pharyngeal nerve; and although the gustatory function of those parts may be chiefly due to the nervous filaments derived from the fifth, still it is believed that the glosso-pharyngeal branches distributed to them are also concerned in the function of taste. In its structure, the mucous membrane in these situations is thinner and looser than that covering the hard palate and gums, and is provided with numerous soft and short papillæ. (See diagram No. 6, p. 85.)

Like the other organs of the senses, the tongue is really a double organ, consisting of two perfectly symmetrical parts joined along the middle line, and provided each with its own set of muscles, blood-vessels, absorbents, and nerves. Its muscular structure, and its consequent mobility and power, have already been explained with the organs of digestion (p. 84).

Fig. 10 is an enlarged view of the upper surface, *dorsum* or *back* of the tongue, as it is called, to show the characters of its mucous membrane.

The back, tip, and edges or borders of the tongue, are closely beset with three kinds of little eminences or projections named *papillæ*, which, as seen in the living person, give it a peculiar rough appearance, quite different from the smooth character of the mucous membrane covering its under surface and the rest of the interior of the mouth.

The most slender, and by far the most numerous kind of papillæ, named the *filiform* papillæ, indicated by the letter *a*, are found closely set over the anterior three-fourths of the tongue, being especially well marked along the central part, but becoming shorter at the sides and tip, where they become arranged in little parallel ridges, which gradually disappear as they run to the under surface of the organ. These filiform papillæ, so named from their thread-like shape, are set for the most part with a slight inclination backwards.

The second form of papillæ, *b*, named *fungiform*, from being expanded at their free extremities, larger than the filiform but not so numerous, are scattered separately from one another over the whole surface of the tongue. They abound more upon its anterior half, being usually rather closely crowded together near the tip, where they are frequently noticeable as little red points, contrasting with the more furred aspect of the surface covered with the filiform papillæ only.

The third kind, marked *c*, are still fewer in number, but larger in size. They are situated upon the back part of the tongue, forming two principal rows, like the letter V with its point turned backwards. Each is placed at the bottom of a cup-shaped depression, so as to be encircled by a little furrow or trench, which being itself surrounded by an elevated rim or diminutive *vallum*, they have been called the *circumvallate* papillæ.

Behind, and on each side of the V-shaped rows of circumvallate papillæ, are numerous largish and soft papillæ, intermediate in form between the circumvallate and fungiform kinds, and, towards the borders of the tongue, passing into irregularly notched and parallel ridges. Still further back, the papillæ subside, and the now smoother and thinner mucous membrane is marked by numerons elevations and recesses, corresponding with the mucous glands and closed follicles already mentioned at p. 85. Thence, this membrane passes over the epiglottis, *e*, and so down into the glottis, *g*, whilst on each side it becomes continuous with that lining the pharynx.

The three kinds of lingual papillæ above described, resemble in structure the papillæ of the skin, in consisting of little prolongations of the vascular and nervous membrane on which they are placed, covered over with an epidermoid or epithelial layer.

Fig. 11 shows these papillæ in enlarged plans, the nervo-vascular basis being coloured pink, and the epithelial layer brown.

The filiform papillæ, *a* (enlarged 70 diameters), present at their points numerous minute prolongations of the nervo-vascular tissue, called *secondary papillæ*, which are covered in and concealed by a *thick* epithelium, split at its free extremity into processes, not unlike minute hairs arranged as if in a little brush. These characters are most evident in the filiform papillæ found along the middle of the tongue. The fungiform papillæ, *b* (enlarged 40 diameters), consist of a club-shaped process of the nervo-vascular basis, prolonged into numerous little conical secondary papillæ, the whole being covered by a soft, smooth, and *thin* epithelium, resembling that of the mouth generally, wholly unlike the horny brush-like epithelium of the filiform papillæ, and allowing the red colour of the blood in the vessels to be seen through. The vascular tissue of the circumvallate papillæ, *c* (enlarged 20 diameters), and of the elevated rim by which each is surrounded, is likewise prolonged into numerous secondary papillæ, which are buried in an epithelial covering, thin and smooth, like that of the fungiform papillæ.

The three kinds of visible papillæ of the tongue, are called *compound* papillæ, owing to their being covered with secondary papillæ. Besides these, there are found everywhere, in the intervals between them, numbers of minute *simple* papillæ resembling the secondary papillæ, and like them, as well as those upon the rest of the mouth, completely concealed or buried in the epithelial covering.

This epithelial coat, when much accumulated, and matted together by the impure secretions of the mouth, constitutes the *fur* upon the tongue,—which, when thus coated, is a useful *tell-tale* of the state of the digestive organs, or of the whole system. The habit of scraping the tongue removes the effect, not the cause of evil. The tongue gives also the earliest warning of the drunkard's tremblings. In scarlatina the epithelium comes nearly all off.

Capillary vessels and nerves penetrate into the simple papillæ of the tongue, and also into the secondary papillæ of the compound kinds. The vessels end in single or multiple loops, according to the size of the papillary eminences. The nerves, with difficulty traced into the filiform papillæ, are very abundant in the fungiform and circumvallate kinds, the precise modes of termination being, however, yet undetermined.

From the thick horny covering, the brush-like ends, and the somewhat backward direction of the filiform papillæ, and from their special development along the middle of the tongue, it would seem that these are intended to aid that organ in holding and turning the morsels of food during mastication. These filiform papillæ, indeed, are the representative in man of the strong lingual spines or processes found in many animals, especially in the cat tribe; and though in the human tongue they are, in comparison, soft and flexible, still it is easy to perceive, by passing the point of the little finger firmly backwards and then forwards upon the middle of the tongue, that a greater resistance is offered to the latter than to the former movement. The filiform papillæ are probably not at all concerned in the sense of taste, though they may be in that exquisite sense of touch, which is possessed by the tongue.

On the other hand, the soft, highly vascular and nervous fungiform and circumvallate papillæ, covered with their thin epithelium, and provided with their hosts of secondary papillæ into all of which the blood-vessels and nerves enter, are well suited both for the function of common sensation and for the gustatory sense. They are, in fact, highly sensitive to touch, to changes of temperature, and to injury; and they both appear also to be the seats of those peculiar impressions which give rise to the sense of taste.

Three nerves are distributed to each half of the tongue, viz., the lingual or gustatory branch of the fifth cranial nerve to the mucous membrane at the fore part and sides,—branches of the glosso-pharyngeal nerve to the mucous membrane at the back part,—and the ninth cranial nerve to its muscular substance. The first two are sensory nerves, the last is exclusively motor. (See pp. 126–7.)

The extremely fine and accurate sense of touch at the tip of the tongue, already noticed, is most undoubtedly due to the sensory filaments of the fifth pair; but the sense of taste is also most acute in the same region, and filaments of the same nerve, as the name gustatory implies, are concerned in that special function. Impressions of taste, especially those which in combination with smell produce *flavour*, are likewise experienced by the back part of the tongue,—and here the glosso-pharyngeal filaments must convey them to the sensorial centre.

Such substances as act only on the common sensory nerves of the tongue are called *tasteless*. Bodies which have a taste, or *sapid* substances, either produce taste alone, as saltpetre, white sugar, quinine, and sulphuric acid, or, what is much more common, give rise to both taste and smell, as smelling-salts, honey, aloes, and acetic acid (the acid of vinegar), which last not only taste, but smell saline, sweet, bitter, and sour. Indeed, what is called the flavour of many substances is incomplete without the aid of smell, as is found by closing the nostrils before swallowing mustard and water, or certain nauseous medicines. Again there are sapid bodies which, besides producing taste, cause *irritation* of various kinds, as mustard, pepper, peppermint, and others,—the stinging, smarting, or burning sensations occasioned by which are probably due in part, if not wholly, to impressions conveyed by the fifth nerve to the common sensorium, and not to the special gustatory nervous centre; but of this we are not certain.

Solution is a condition necessary to taste, for insoluble substances, such as glass, are all tasteless, and even sapid substances, if applied dry to a dry tongue, produce no taste: hence one great use of the saliva, which is excited to flow as soon as anything is taken into the mouth, especially if it have flavour. Perfect contact is also essential, and hence flavours of all kinds are remarkably developed by pressing the substance or fluid to be tasted between the mobile *tongue* and the *palate*, as is done in the smack of the *bon-vivant*, and of connoisseurs, judges, and dealers in wine, fruit, and some other articles.

The discriminating powers of the sense of taste, are soon confounded when two or more allied flavours, such as those of different wines, are presented to the tongue alternately or in succession, partly, perhaps, from some continuance of each impression, but, in all probability, chiefly from small quantities of the dissolved sapid substances remaining in the epithelial coat. Contrasted flavours, however, help each other.

The sense of taste assists us in the preference of food, and superadds the agreeable enjoyment of relish to the acts of eating and drinking. It probably also, as already hinted at, excites, by reflex influence on the sympathetic nerve (p. 138), a more abundant flow of saliva than would take place without it. Independently of experience, taste may deceive us as to the noxious or inocuous quality of food; but, certainly, when not hardened or vitiated, its acts as a guardian in preventing too much overheating food from being taken into the stomach; and in the case of invalids, the suggestions of the sick man's palate are often safer than the *dicta* of the medical adviser. In animals the sense of taste is probably, on the whole, a more trustworthy guide than in ourselves.

Cultivation may *improve* this, like the other senses, as is noticed in the case of wine and tea-tasters. Habit leads to *acquired* tastes, as, for example, those for rotten cheese, putrid game, and tobacco. Next in degree of vitiation are the *morbid* tastes manifested in cases of mental disease. Taste and smell, functionally associated, are often lost together, either temporarily from cold, or permanently from injuries or defect in the brain.

THE ORGAN OF SMELL.

THE NOSE AND ITS CAVITIES.

Figures 12 to 24.

As touch chiefly recognizes external solidity, and taste detects flavours dissolved in the mouth, so the sense of smell exercises its office on odorous particles, either suspended, or, as it were, held in solution in the air, or themselves actually in the gaseous or aëriform state. Hence the *nose* and its *cavities*, the parts superadded to the olfactory nerves, or special nerves of smell, are open to the atmosphere, form the proper inlets to the air-passages, as the mouth does to the food-passages, and thus take constant part in the respiratory act. They furthermore assist in the resonance of the voice, and in the production of certain of the articulate sounds of speech.

In its construction the nose is a double organ, consisting, internally, of two symmetrical and exceedingly complicated cavities, separated from one another in the middle line by a complete partition or *septum.* These cavities are placed deeply beneath the forepart of the cranium and above the hard palate, in the midst of the bones of the face, which, indeed, serve to form their solid boundaries. The nasal cavities communicate with a series of secondary cavities, called *sinuses*, formed in the surrounding frontal, ethmoidal, sphenoidal, and superior maxillary bones. Moreover, they open in front and behind by double apertures, called the *anterior* and *posterior nares.* (See diagram No. 1, figs. 1 and 3, and the description in pp. 4 and 6.)

In the perfect state, the nasal cavities are prolonged forwards by the cartilaginous or gristly part of the nose, and as well as the various sinuses with which they are in communication, are closely lined throughout with a fibrous membrane or periosteum, covered by a firmly-adherent mucous membrane, and present the appearance represented in diagram No. 6, fig. 3, *n.* In this state the *nostrils*, where the mucous membrane is continuous with the skin, form the anterior openings of the nasal cavities, whilst the posterior nares, diagram No. 6, fig. 4, *n*, where the same membrane is continuous with that lining the pharynx, form the hinder outlets.

Fig. 12, in the present diagram, represents the outer wall of the right nasal cavity, the median septum having been removed with the parts belonging to the left side: *a*, *b*, *c*, are on the superior, middle, and inferior turbinated or twisted bones, from which the mucous membrane is so far dissected as to show the ramifications of the olfactory nerve, the bulb of which is marked *ob*, and also some branches of the fifth cranial nerve, 5. This section passes through the frontal sinuses in front, the sphenoidal sinuses and the upper part of the pharynx behind, and the hard and soft palate below.

Fig. 13, which is a transverse section through both nasal cavities, from the floor of the cranium above to the roof of the mouth below, shows the median partition or septum, *s*, between the two nasal cavities, the middle and inferior turbinated bones, *b* and *c*, the ethmoidal sinuses, *e*, and the superior maxillary sinus, *m.*

The internal surfaces of all these parts being covered by the nasal mucous membrane, the complex forms of the upper and middle turbinated bones serve to increase the olfactory surface used in smelling; the various sinuses amplify the sources from which mucus or moisture may flow gradually over the interior of the nose; and the whole arrangement is adapted to warm and moisten the air passing to the respiratory organs, and to give resonance to the voice.

In animals having the sense of smell very acute, especially in the hunting carnivora, the turbinated bones are composed, in some cases, of an amazing number of thin laminæ, on both sides of which the mucous membrane is spread out, so that the smelling surface is immensely increased.

Fig. 14 represents the mode in which the cartilages of the nose fill up the somewhat ill-favoured void in that part of the dried skull: *m* is a portion of the upper jaw-bone, showing the inner margin of the left orbit, in which is the lacrymal groove, *l*, to be hereafter described; *n* is the left nasal bone, and *c* marks the cartilages belonging to the left side of the nose. The outer rim of the nostril, or lower border of the wing or *ala* of the nose, as it is called, though supported above by little cartilages, is composed only of thick skin, containing granular masses of fat, and many large sebaceous glands. Within the nostrils are the short protective hairs, called *vibrissæ*.

The projection of the nasal *bones* is a peculiarly human characteristic, and the complete organ, with its subcutaneous muscles, the *pyramidalis nasi*, the *compressor of the nose*, the *levator* of the *nose* and *upper lip* (diagram No. 2, fig. 1, p. 24), and several small slips which move the cartilages one on the other, forms an important feature in the human countenance, serving as one of the many distinguishing marks between man and brutes, constituting a special ornament to the face, and participating also in the expression of certain emotions, chiefly of a violent kind.

The nasal mucous membrane, called the *Schneiderian membrane*, differs in structure at different points. Near the nostrils, indeed, it is more like a very thin skin, being provided with papillæ and covered by a dry but very thin epidermis.

Further in, on the floor and on the sides of the lower portion of the nasal cavities, and in all the sinuses, the mucous membrane is thin and red, and its epithelium, like that of the larynx, trachea, and the other air-tubes, is *ciliated*, *i. e.* is provided with the little vibrating organs called *cilia*, such as are figured in diagram No. 9, fig. 79. This lower *region* may be regarded as the *air-tract* or *respiratory region* of the nose, or as a portion of the general air-passages. It is highly sensitive, the smallest particles of acrid foreign matter, whether solid, fluid, or gaseous, causing immediate irritation, and often exciting the consensual reflex act of sneezing for their expulsion. As shown in fig. 12, it receives common sensory branches from the fifth nerve, 5, but none from the olfactory nerve, 1. If the fifth nerve be divided or paralysed, sneezing no longer takes place, whereas if the olfactory nerve only be divided, it still takes place, showing that this act is excited through the branches of the former.

In the upper regions of the nasal cavities, corresponding to about the upper third of the septum, and to the whole of the superior and middle turbinated bones, the mucous membrane is thicker and softer, has a peculiar yellowish colour, and is covered with a comparatively thick and closely-set epithelium, laminated, somewhat columnar, but destitute of cilia. This is the *olfactory region* to which, see fig. 12, the ultimate branches of the olfactory nerves are distributed, and is, therefore, the seat where odorous particles reach those nerves. It is provided with peculiar glands, somewhat resembling the sweat-glands but finer in structure; whereas the larger glands, abundantly scattered over the non-olfactory region, are the ordinary branched mucous glands. The branches of the olfactory nerves are soft, of a greyish colour, and have a granular texture, in which no tubular fibres exist; they form a close network beneath the thick, non-ciliated epithelium. Their mode of termination is not known, but it has been stated that they have been traced towards the surface between the cells of the epithelial layer.

Although odorous substances enter the nose mixed with air, or in an aëriform state, it seems certain that they are liquefied at the surface of the epithelium, ere they actually reach the fine extremities of the ultimate twigs of the olfactory nerves. In a dry atmosphere odours are not so easily recognized as in a damp one; and besides this, a certain state of moisture of the mucous membrane is necessary to smell, that sense being certainly defective, and perhaps inoperative, when the interior of the nose is quite dry. This reminds us of the similar condition of moisture indispensable to tasting. It has been noted, in the account of the respiratory process (p. 46), that before gases can pass through a moist membrane they must first be liquefied or dissolved; and in the process of smelling, some such solution in the moisture of the olfactory mucous membrane doubtless takes place, in regard to odorous substances, whether these are in a state of minute particles, vapours, or gases.

Too great a flow of secretion from the nasal mucous membrane, however, as happens in the case of a severe cold, is associated with a partial or total loss of smell, either owing to the odorous substances being, as it were, washed away, or to some accompanying change in the vascular or nutritive conditions of the part, unfavourable to the action of the olfactory nerves. It is curious that at the same time the common sensibility of the mucous membrane is intensified,—even a sniff of cold air being very painful, and liable to cause sneezing.

From the nose being capable, like the tongue, of appreciating, through its special and its common sensory nerves, two kinds of impressions, it follows that not only do some substances act as simple irritants and others as simple odours, but many may operate in both ways, causing some peculiar smell, and also a smarting or pungent sensation. A solution of salt belongs to the first class, the delicate odours of certain flowers and fruits to the second, and such substances as mustard, acetic acid, and smelling-salts, which undoubtedly act on both kinds of nerves, to the third. As muscular actions are called into play to aid the sense of taste, as in smacking the tongue and lips, so the act of sniffing, which is a mixed respiratory and nasal muscular effort, is used to bring odorous substances more surely and extensively into contact with the upper and proper olfactory region of the nose, besides causing a larger amount of them to pass over the mucous surface in a given time. There are, on the whole, many analogies between taste and smell; and the necessity of smell to the complete realization of certain flavours, which might be called odour-tastes, has already been alluded to.

The smell aids us, like the taste, in the choice and enjoyment of food, and may assist in the excitation of flow of saliva. As taste guards the stomach, so smell warns us, even of the distant approach of noxious substances which would be injurious to the lungs, or otherwise detrimental to health. It may not recognize the actual miasms of disease, but it does detect those unwholesome conditions of the atmosphere, loaded with impurities, which are favourable to the development of such poisons. The unsanitary customs of civilized life so blunt its delicacy in this respect, that it ceases to act as a guardian in many cases. By the continued operation of any one odour, whether agreeable or disagreeable, healthy or unhealthy, the power of perceiving it is destroyed, at least for a time; but a breath or two of fresh air soon restores the exhausted olfactory nerve or nervous centre. The impressions of the sense of smell, like those of taste, are often remarkably permanent. In blind people, this sense is often so cultivated, that they can distinguish persons by it. There are some people who, owing to what are called idiosyncrasies, suffer in the most singular manner, from certain odours, as from the smell of ipecacuanha or of cats.

THE ORGANS OF HEARING.

THE EARS.

Figures 15 to 18.

The organs of hearing, placed one on each side of the head, consist of very beautiful and complex acoustic apparatuses, superadded to the extremities of the auditory nerves, for the purpose of receiving, conveying, and transferring to those nerves the peculiar vibrations of matter, which are the physical cause of sound,—in other words, the impressions produced by which in our sensorium are interpreted by us as *sounds*.

The auditory apparatus is usually and conveniently described as consisting of three parts, named respectively, the external, middle, and internal ear,—the general characters and mutual relations of which can easily be understood by reference to fig. 15 in this diagram, which is a planned section through the various parts on a large scale.

1. Under the term, *external ear*, are included the *auricular appendage*, *b*, usually called the ear, and the tube or passage, *m*, leading from it into the temporal bone, *p i*, named the *external auditory meatus* or *canal*. At its inner end, this canal is closed by a nearly circular membrane, one half of which only, marked *d*, is seen in the sectional plan.

2. Beyond this membrane is a small chamber in the temporal bone, called the *tympanum*, or *drum of the ear*, which with its contents,—certain small bones or *ossicles*, a few muscles and nerves,—constitutes the *middle ear*. The circular membrane, *d*, just mentioned, which separates the tympanic cavity from the external meatus, is called the *membrane of the tympanum*, *membrana tympani*, and from its likeness to a miniature drum-head, has suggested the name given to this part of the auditory apparatus. On the inner wall of the tympanum is a smaller circular membrane, which shuts in a *round opening* in the bone, and which might be compared to the other head of a drum; besides which, there is an *oval aperture* on the inner wall of the tympanum, closed partly by a little bone, and partly by a membranous structure. The middle ear or tympanum communicates behind and above with cells in the temporal bone, *i*,—those behind, lying in the mastoid process, being called the *mastoid cells*. In front and below, it opens into a long passage called the *Eustachian tube*, *e*, which leads into the upper part of the pharynx. The internal carotid artery goes through a canal in the bone marked *a*, very near this tube.

3. Beyond the tympanum is the *internal ear*, also called the *labyrinth*, which consists of

certain complex *chambers* and *canals*, *s*, *c*, each inclosing certain membranous and fluid contents, and all so bedded in the substance of the petrous part of the temporal bone, *p p*, that this, as represented in the figure, has to be chiselled away very carefully in order to display them. Beyond, and corresponding with the inner side of the labyrinth, is the bottom of the *internal auditory meatus*, seen on the internal surface of the petrous part of the temporal bone, diagram No. 1, fig. 3, C (see also p. 6), through which the auditory nerve passes to enter the labyrinth itself. The labyrinth, indeed, is the most essential part of the organ of hearing; for here it is that the vibrations which give rise to the sensation of sound, actually impinge upon the extremities of the auditory nerve.

The parts composing the external, middle, and internal ear, may now be more particularly examined, in order that their functions, so far as these are at present understood, may be subsequently explained.

The External Ear.

The part vulgarly called the ear, is named by anatomists the *pinna* or *auricle*. Its curious but beautiful shape is sufficiently familiar to all. The outer rim or border, absent in badly-formed ears, is called the *helix* (a roll); a curved ridge internal to this is the *anti-helix*. Within this is the principal fossa or hollow, called the *concha* (a shell), *b*, which leads directly into the external auditory meatus.

The opening into the meatus is overlapped in front by a flattened projection, which is commonly studded with hairs standing across that orifice, and which from a fancied likeness to a goat's chin and beard, is called the *tragus*, τραγος, a goat; opposite to this is another eminence, called the *anti-tragus;* between them is a deep notch, leading into the concha, and below the notch is a soft pendulous part, peculiar to the human ear, called the *lobule*.

The framework of the auricle is formed of a firm, elastic cartilage, having nearly the same shape and varieties of surface as the perfect auricle, but it does not extend into the lower part of the posterior border, nor into the lobule, which consists of a fold of skin with fat and dense areolar tissue only. This cartilage is fissured in certain places, which enables it to be pulled or folded, and again recover its position or form. Passing across the fissures, are found fibrous bands, and here and there some minute muscles. There are also, besides some fibro-elastic tissue, three small muscles, marked 2 in diagram No. 4, fig. 1, which pass from the side of the head to the back of the auricle; but though these can be used voluntarily by some persons, they, as well as the little muscles upon the auricle, are small in comparison with those of the more moveable ears of animals. The skin of the auricle is neatly and closely fitted to it, especially within the concha, where it contains many sebaceous glands.

The *external auditory canal* is a slightly-curved tube, measuring about 1¼ inch long from the concha to the membrana tympani, which closes it at the inner end. Its upper side is somewhat concave, but its under one is convex, and owing to the slanting direction of the membrane of the drum, somewhat longer than the former. The meatus is narrowest in the middle part; hence arises a difficulty in the extraction of foreign bodies, although they may be quite moveable beyond that part. The outer half of the meatus has cartilaginous, and the inner half bony, walls. The cartilaginous portion is partly continuous, but mostly connected by ligament with the cartilage of the auricle, on the one hand, and on the other, is fixed strongly to the outer margin of the deeper bony part, the opening of which is shown at J, in fig. 3, diagram No. 1. The skin lining the meatus, which is continuous with that within the concha, is closely adherent, and gets much thinner towards the bottom of the canal, where it is prolonged over the membrane of the tympanum; so that, after sufficient maceration, its cuticular layer may be drawn out in the form of a blind pouch. In the cartilaginous part of the meatus the skin is provided with fine hairs and numerous little yellowish glandular bodies, called the *ceruminous glands*, which somewhat resemble the sweat-glands in their structure, and secrete the *Cerumen* or *wax of the ear*.

The Middle Ear or Tympanum.

The membrana tympani, which closes the bottom of the meatus, and forms the outer boundary of the cavity of the tympanum or drum of the ear, is thin, semi-transparent, and about the colour of white tissue-paper; as shown in fig. 16, *d*, which is a view of its inner or tympanic surface, it is fixed all round to a slight groove in the bone, *r;* and, besides sloping downwards and inwards, it is slightly drawn in as it were towards the tympanum, owing to one of the little bones, *a*, of the tympanum being attached to the inner surface, near the centre. It is composed of an outer layer, which is a very delicate extension of the skin of the meatus, of an inner layer, similarly derived from the mucous membrane lining the tympanum, and of an intermediate proper layer, consisting of fibrous and elastic tissue, in which are blood-vessels and nerves. Its fibrous tissue is chiefly arranged in bundles, radiating from near the centre of the membrane; but there are circular fibres at the margin.

Stretched across the drum of the ear, from the membrane of the tympanum to the inner wall of that chamber, are the little bones or *ossicles of the ear*, the smallest in the body, yet most elegant in shape and beautifully modelled. They are three in number, named according to their forms, the *malleus*, or *hammer*-like bone, fig. 17, *a*, its handle being marked *h*, the *incus*, or *anvil*-like bone, *b*, and the *stapes*, or *stirrup*-like bone, *c*. A little nodular projection, *o*, on the longer leg of the incus was formerly regarded as a separate bone, and called the *orbicular* bone. The position of these bones within the tympanum is shown in figs. 15 and 16. The malleus, *a*, is fixed widely by its *handle* to the inside of the membrana tympani; its long process, called the *processus gracilis*, descends to the floor of the tympanum, whilst its rounded part or head, which is also somewhat fixed to the roof of that cavity, is articulated with a concave surface on the thick part of the incus. This bone, marked *b*, besides being articulated to the malleus, is attached by its shorter leg to the hinder wall of the tympanum; whilst by the little tubercle or orbicular bone, *o*, it is articulated to the third or innermost bone, the stapes. The stapes, *c*, is placed horizontally, and is attached by its foot-piece or base (turned towards the spectator in fig. 16) to the inner wall of the tympanum, where it serves together with a ring of ligamentous tissue to completely fill up an oval aperture in the bone, called the *fenestra ovalis*, leading to the internal ear or labyrinth; yet it is so attached as to be able to perform certain movements. The foot-hole in this diminutive stirrup is closed by a membrane in the perfect state. These little bones weigh only a few grains, the length of the stapes being not quite $\frac{1}{6}$th of an inch; nevertheless, they are covered with periosteum, are supplied with blood-vessels, are articulated together by perfect joints, having cartilaginous surfaces, synovial capsules and ligaments, and, lastly, they are provided with minute muscles, which, acting on the little levers formed by this jointed rod, influence the condition of the membrana tympani on the one hand, and of the ligamentous ring which unites the base of the stapes to the margin of the fenestra ovalis on the other.

Of these muscles, which arise from definite points of the surrounding petrous bone, two go the malleus,—one called the *tensor tympani*, which tightens and draws the membrana tympani inwards,—the other, smaller, named the *laxator tympani*, which is supposed by some to have an opposite action; but this is doubtful. A third little muscle, the smallest in the body, measuring about $\frac{1}{5}$th of an inch in length, and about $\frac{1}{15}$th of an inch at its widest part, goes to the stapes. It is called the *stapedius;* and through its action on that bone, it probably determines the state of tension of the parts closing in the fenestra ovalis. Other reddish structures within the tympanum have been described as muscles, but they appear rather to be ligaments fixing the little bones.

On the inner wall of the tympanum, below the oval fenestra which is occupied by the base of the stapes, is another small rounded opening in the bone, called the *fenestra rotunda*, seen just above *t*, in fig. 15, which in the recent state is also shut in, but by membrane only. On the inner, or deeper, side of the parts closing both these openings are the cavities of the internal ear, or labyrinth.

The tympanum is lined throughout by a delicate mucous membrane, which is for the most part provided with cilia. It assists in closing the oval and round fenestræ; it is reflected over the little ossicles and the tendons of their muscles, and also over the chorda tympani nerve, which runs across the tympanum (see p. 126); and it serves to form the inner layer of the membrana tympani, in which last situation it is said to be destitute of cilia. It contains no mucous glands, but it is constantly moistened with a yellowish fluid. It enters and lines the *mastoid cells*, with which, as already mentioned, the tympanum communicates behind; and in front it is continuous with the ciliated mucous membrane lining the *Eustachian tube*, and so with that of the upper or respiratory portion of the pharynx.

This tube, fig. 15, *e*, named after Eustachius, an old anatomist, is a trumpet-shaped canal (*tuba*, a trumpet), about 1½ in. long. The part nearest the tympanum is formed in the petrous part of the temporal bone, but the pharyngeal end has a cartilaginous framework. Its mucous membrane is supplied with many little glands.

The Internal Ear or Labyrinth.

Figures 15, 18, and 19.

Of the complicated cavities buried in the petrous part of the temporal bone, which form the *bony labyrinth*, one, a sort of central chamber, of an oval shape, and capable of holding a grain of pearl barley, is called the *vestibule*. It is situated just opposite the fenestra ovalis and base of the stapes. Communicating freely with it are the three curved channels named the semicircular canals, and also the cavity of the coiled part named the cochlea.

The *semicircular canals*, figs. 15 and 18, *s*, designated, according to their position, *vertical*, *horizontal*, and *oblique*, are bent tubes about $\frac{1}{20}$th of an inch in diameter, each having at one end a dilated part called the *ampulla*, which is about twice as wide. As two of these tubes join together at one end, the three communicate with the vestibule by *five* openings.

The *cochlea*, figs. 15 and 18, *c*, is a little spiral canal, with bony walls, resembling a small snail's *shell*, whence its name. From base to apex, it measures about $\frac{1}{4}$th of an inch. When cut through in that direction, as shown in fig. 19, it is seen to have a sort of bony axis, called the *modiolus*, formed as it were by the coalescence of its spiral turns. From the sides of the modiolus projects a thin bony plate, turning round the modiolus like the thread of a gimlet; from the margin of this, in the recent state, a membrane proceeds quite across to the outer walls, *a*, of the spiral turns. By this partly bony and partly membranous lamina, called the *lamina spiralis*, *b*, the turns of the cochlea are divided internally into *two* semi-cylindrical spiral canals, called the *scalæ* (staircases), which, however, communicate at the summit or *cupola* of the cochlea, where the lamina spiralis is defective or terminates by a free curved edge. At the base of the cochlea, one of the scalæ, called the *vestibular scala*, opens into the vestibule, as shown in fig. 18, where all the cavities of the labyrinth are laid open; whilst the other, called the *tympanic scala*, ends on the inner wall of the tympanum, at the fenestra rotunda, seen just above *t*, in fig. 15, which aperture, as already mentioned, is shut by a thin membrane only.

When laid open, as represented in fig. 18, the vestibule and semicircular canals are seen to contain membranous sacs and canals, which constitute what is called the *membranous labyrinth*.

In the vestibule are two sacs, a smaller one called the *saccule*, lying near the entrance into the cochlea, and a larger one named the *common sinus* or *utricle*, placed near the openings of the semicircular canals, which themselves contain the three membranous semicircular canals, having their respective ampullæ, and opening into the utricle itself.

The walls of the saccule, utricle, and membranous canals, are firm and semi-transparent; they consist outside of a loose vascular layer with pigment cells, next of a thick glassy-looking fibrous tunic, and internally of a layer of polygonal epithelium. All these parts contain a limpid fluid, almost pure water, but slightly albuminous, called the *endolymph.* Within the walls of the saccule and the utricle are two roundish clusters of crystalline particles of carbonate of lime, called *otolithes* or *otoconia*, that is, ear-stones or ear-dust, of which a few scattered particles also exist in the membranous canals and ampullæ. This otoconia is connected with the ends of the vestibular part of the auditory nerve, as will be immediately described.

The membranous labyrinth does not completely fill the corresponding parts of the bony labyrinth, and the interval between them, as well as the entire cavity of the cochlea, which contains no membranous sacs or canals, is occupied by a thin slightly albuminous liquid, called the *perilymph*, which most resembles the sub-arachnoid fluid of the cranium. All parts of the labyrinth are lined by a delicate membrane, which besides secreting this fluid, is reflected over, and so supports, the sacs, the canals, and the nerves which go to them.

The outer or membranous part of the lamina spiralis of the cochlea is semi-transparent, and marked with lines radiating from the axis of the cochlea. Its outer margin is said by some to be attached by involuntary muscular fibres, forming what is called the *cochlear* *muscle*, which by others is regarded as ligamentous only. This membranous zone is fibrous, vascular and nervous. In the tympanic scala its surface is smooth; but in the vestibular scala, fig. 18, it presents a very remarkable structure called the *denticulate* or *toothed lamina.* Near the base of the cochlea, this is wide and rests chiefly on the bony lamina, but as it is traced to the apex, it becomes narrower, and at last rests on the membranous zone only. Amongst other microscopic elements, it contains two series of minute *rod-like processes*, arranged in a radiating manner from the osseous zone, and ending in the membranous zone in two rows of little *tooth-like projections*, the whole being covered by the delicate lining membrane of the labyrinth, which is bathed with the perilymph. This very beautiful structure is connected with the terminations of the cochlear branches of the auditory nerve.

The *auditory nerve*, fig. 18, *n*, or soft portion of the seventh cranial nerve (see p. 126), having reached the bottom of the internal auditory meatus, corresponding with the vestibule and the base of the cochlea, breaks up into numerous cords, which, supported by tubular sheaths of the dura and pia mater, pass through minute holes in the bone. Having traversed the bone, those which are intended for the saccule, utricle, and membranous semicircular canals are gathered within the labyrinth into five bundles, which, invested and supported by the lining membrane of that cavity, and surrounded by the perilymph, pass to their respective destinations. Two of them pierce the walls of the saccule and utricle at the situations of the otoconia, some of their fibres spreading out on the inner surface of the glassy tunic, whilst others, passing amongst the earthy particles, end in free points. The three others reach the convex side of the three membranous ampullæ, and first forking out sideways, penetrate the walls of those parts opposite a sort of transverse partition in their interior, and then end in free points, and perhaps also in some other way. As to the cochlear nerves, their little component cords, having entered minute holes in the bone, pass along numerous small canals running up the modiolus, and thence diverge laterally in regular succession along other little channels formed in the bony part of the lamina spiralis, near the margin of which they unite in a sort of plexus, mixed up with ganglionic nerve cells. Radiating into the membranous zone of the spiral lamina, they end mostly in the side turned towards the vestibular scala, becoming connected in some way with the terminal series of little toothed rods already described.

Functions of the Internal, Middle, and External Ear.

Sonorous vibrations, or vibrations capable of exciting the sense of sound, may originate in solid, liquid, or aëriform bodies, may be propagated to us through either of those media, and may reach the auditory nerves either through the framework of the body and head, or else through the special auditory apparatus.

In the animal kingdom generally, the organ of hearing is modified in structure according to the various modes in which sounds have to reach and act upon it; but even in the most rudimentary condition, the part first superadded to the sensitive extremities of the auditory nerve, clearly typifies the central chamber of the internal ear, or vestibule of the labyrinth.

Amongst the higher invertebrata, in the snails and cuttle-fish, and also in the crab tribe, auditory sacs of various complexity are found; but the organ is of far less importance than in the vertebrata.

In fishes, to which animals sounds are entirely conducted through water, the vestibule always contains an utricle, and generally a saccule as well, each with its included otolithe or ear-stone. To these are added either some imperfectly-developed channels representing semicircular canals, or one, two, or, more commonly, three perfect canals, of large size, and ending as usual in the vestibule. In the higher kinds there is also an oval fenestra. The walls of these parts are either cartilaginous or bony, according to the character of the fish's skeleton. They usually project into the cranial cavity, and only in the higher forms are partially lodged in the temporal bone. The cochlea is absent, so that even the internal ear is incomplete; and there is no middle ear or tympanic chamber, and no external ear. In the rays and skates there is, however, a foreshadowing of a communication with the exterior, in the shape of a canal leading from the internal ear to the skin near the back of the head.

In the aquatic batrachia, as the proteus, the condition of the ear is fish-like; but in the air-breathing frog, toads, and newts, which also receive sounds propagated through the atmosphere, there is, in addition, a small tympanic cavity, closed by a membrana tympani level with the side of the head, crossed by a single ossicle resting on an oval fenestra, and communicating with the back of the throat by a little Eustachian tube. There is still no cochlea.

In the reptiles, all the parts of the labyrinth are represented, for now a rudimentary cochlea first appears, consisting of a short, conical, straight or slightly-curved canal, divided by an internal septum into two scalæ, communicating with each other at the apex of the cone, and ending at the base, one in the vestibule, and the other at a closed round fenestra on the wall of the tympanum. The tympanum, imperfect in serpents, is large in the crocodiles; there is still but one long ossicle, called the columella; no tympanic muscles have yet been noticed; the membrane of the drum is a little sunken on the side of the head.

In birds, besides the vestibule and semicircular canals, there is a decidedly curved, but not spirally twisted, cochlea. The tympanic ossicle is single, but there is a distinct tensor tympani muscle. An external meatus is obvious, but there is no auricle, only a radiated arrangement of the feathers, or a few flaps of skin around the aperture.

In the monotremata and marsupials, the auditory apparatus approaches closely the mammalian type, which latter is in all particulars founded on the same plan as the human ear,—having a spiral cochlea, three ossicles with their muscles, a large external meatus, and more or less of an auricle.

From these facts it is evident, that in the case of animals living entirely in the water, the internal ear, without a cochlea, is alone concerned in the reception of sounds, which are conveyed to the head of the animal through that medium; and secondly, that in the case of animals hearing through the air, a more or less perfect tympanum, a rudimentary or perfect cochlea, and lastly, some sort of external ear, are successively superadded.

To understand the reasons for these different provisions, it is necessary to bear in mind some of the general principles which regulate the *propagation* and *reflection* of sounds. Sonorous undulations pass most readily from solids to solids, rather easily from water to solids, but with very considerable loss from air to solids. From solids, sounds pass readily to water, but not so easily to air. From water to air and from air to water the sound-waves pass with very great difficulty. The chief impediments to transmission occur, therefore, in the passage of sound-waves to and from solids and air, and to and from water and air; but it is remarkable enough that with a peculiar arrangement of solid materials, namely, in the form of *elastic membranes*, which may be regarded acoustically as expanded cords, those difficulties to a great extent cease. Thus, stretched and dry membranes are easily made to vibrate by sonorous undulations in air, and easily excite them in air in return; but moist membranes scarcely act at all. It is also found that by interposing a stretched membrane between water and air, the transmission of sound-waves in either direction is greatly facilitated. In both these cases the combination of some perfectly solid body with the membrane increases the facility of the passage, though still it is less easy than that to and fro between solids and water. Finally, it must be noted that when sonorous undulations pass from solids to water, they appear in some way to reinforce those in the water itself, especially in the neighbourhood of the solids in question.

Now, in the construction of the auditory apparatuses of aquatic and air-breathing animals, the operation of the foregoing general principles has been studiously and wonderfully regarded.

In the case of fishes, sounds pass readily from the water to the solid framework of their heads, and thence readily also to the perilymph, sacs, and endolymph of their auditory vestibules, where, intensified by the action of the usually solid, but in some cases pulverulent otolithes, they impinge on the extremities of the auditory nerves.

In air-breathing animals, and in our own ears, which may henceforth serve us for illustration, sounds excited in the atmosphere reach the water of the labyrinth in two ways: first, through the solid bones of the head; and secondly through the mixed membranous and osseous tympanic apparatus. The former passage is effected with difficulty, or the noises which would thus continually reach us would not only confuse those received through the tympanum, but would be unbearable if not deafening. The latter passage is accomplished readily, and with great range and delicacy of appreciation.

There are certain sounds produced by the concussion of solids against solids, which, in our own case, reach the labyrinth directly through the cranial bones. Such are the noises produced in eating, by striking the teeth together, by tapping the teeth ever so lightly with a hard body, by holding a vibrating tuning-fork against the teeth or sides of the head,—even after its first sound has ceased to be distinguishable through the air alone,—also by holding one end of any conducting substance between the teeth, whilst the other end is being scratched, and lastly by holding a watch between the teeth. On a principle to be presently explained, all such sounds are rendered louder by stopping up the ears. Many loud sounds produced by vibrations in the air powerful enough to affect the walls of the head, as the noises heard—or, one may say, felt—in a railway-carriage, the loudest notes of an organ, the report of artillery, the sounds of earthquake and thunder, are also in part conveyed directly by the temporal bones to the labyrinth, as well as by the tympanum,—for they are still heard when the ears are tightly closed.

In reference to such sounds as are thus directly conveyed to the labyrinth through the cranial walls, the chief share in general audition is attributed to the contents of the vestibule; whilst it is thought that the semicircular canals which on each side of the head occupy positions or planes corresponding with the three dimensions of a cube, are concerned in the appreciation of the *direction* of such sounds, and perhaps also of those coming through the tympanum. The otoconia of man and the higher animals, like the otolithes of fishes, are supposed to intensify the sonorous vibrations at or near the extremities of the auditory nerves. The cochlea, buried in the solid bone, and provided with nerves passing through its solid modiolus and spreading out upon its spiral lamina, is thought by some—though this view is not universally admitted—to be peculiarly adapted for receiving sounds conveyed through the cranial walls, forming, in fact, in animals living in the air, an apparatus for intensifying the vibrations coming to the walls of the head from the atmosphere, which is not wanted in the case of fishes, as they are surrounded by so much better a conducting medium for sound.

For by far the greater number of air-borne sonorous undulations, however, the proper inlet is the external ear, and their proper path to the labyrinth is through the tympanum or middle ear; and the actions of the various constituent structures of these parts serve to illustrate certain other principles concerning the diffusion of sonorous undulations, which have not yet been mentioned. In the first place, when atmospheric sound-waves strike on the surface of any opposing body, they are partly turned back, or, as it is called, *reflected* from it; and in some cases, as when the body is solid, fixed, and very rigid,—as a wall, or rock,—the reflection is almost wholly complete. Echoes depend on this principle. The angle at which the sound-waves are reflected equals that at which they strike a given surface; or, as it is said, the angle of *reflection* is equal to the angle of *incidence*.

All the atmospheric sound-waves, however, are not thus reflected; for some operate by communicating to or exciting in the body struck, according to its elasticity or susceptibility, similar vibrations to their own. In the case of *communication*, there is simply a conveyance of sound from one medium to another, after the modes already explained; and this kind of transfer is common to all sounds, whether noises or definite tones, the difference between which consists essentially in the one being caused by *irregular* undulations, and the other by a *succession* of regular sonorous waves. The *excitation* of sounds by one body in another is different, for in its purest forms it occurs only with regular or definite tones, and requires that the natural note, given out by the exciting and excited body when struck, or otherwise sounded, shall be identical. This action, which is called the reciprocation of sounds,—the sounds themselves being called *reciprocal*, and the bodies *reciprocating*,—is observed when two strings tuned to the same note are placed side by side, and one of them is sounded by a fiddle-bow; on doing which the other is immediately thrown into corresponding vibrations and emits the same note. Dry, stretched membranes, which, as before observed, may be regarded acoustically as expanded cords, also reciprocate their corresponding or natural sounds. Again, there is another and less pure form of excitation of sounds, called *resonance*, when one sounding body excites not its own fundamental note, but others having certain harmonious relations to it, in another body, or in parts of another body,—as when a tuning fork, sounding a given musical note, is placed on a sounding board, a table, a glass window, or a wooden floor, having different fundamental notes, or no proper note at all. In this case, the second bodies *resound*, as is commonly said; and they are called *resonant* bodies. In this sense, even air is a reciprocating and resonant body, especially when shut up in closed chambers, or contained in isolated columns, as in open glasses or in tubes of various materials, as glass or organ pipes, in which case, if the sizes of the glasses and widths and lengths of the tubes are so arranged as that the fundamental note of the contained column of air thrown into vibration agrees with that of a tuning-fork struck and held over its mouth, the corresponding note is produced in the glass or pipe by a pure reciprocal action. The peculiar sonorous effects produced by shouting or whistling a particular note, in a tunnel, archway, cavern, or room, having a corresponding fundamental note, also depend on resonance more or less exactly reciprocal, produced in the contained air.

Reverting now to the functions of the several parts of the external and middle ears, it is obvious, in the first place, that the auricle, from its position, size, and projection outwards from the head, from its general concavity being turned somewhat forwards, from its firm, dense structure, the smoothness and tightness of its skin, and especially from the relation of its concha to the external meatus, receives and reflects the atmospheric sound-waves into that tube, which as evidently conducts them, through vibrations in its contained air, on to the membrane of the drum. The conducting office of the meatus is proved by the impairment or loss of the power of hearing sounds coming through the air, caused by stopping it with the finger end, or by its obstruction with ear-wax, cotton-wool, oil, or water. From the partial concealment of the outer end of the meatus and the bent direction of that tube, the membrane of the drum cannot be seen when the parts are in their ordinary position. Hence, also, the atmospheric sound-waves cannot pass straight down from without to that membrane, but must be reflected many times and at various angles, chiefly from the surfaces of the concha and interior of the tragus down into the meatus, and from all sides of that tube, through its contained air, on to the membrana tympani.

Besides thus reflecting atmospheric sonorous undulations, the auricle and meatus must also *conduct* a certain number through their own cartilaginous and bony walls to the margin of the membrana tympani, and even through the temporal bone directly to the labyrinth; and this perhaps affords some explanation of the various and singular disposition of the surfaces of the auricle, which, though supposed by some to be so arranged as to receive at right angles, and therefore favourably for complete conduction, sound-waves from all directions, may be rather intended to meet the slighter ones in such opposite and conflicting directions as to enable them to neutralize each other, and so not confuse those properly conveyed to the membrane of the drum through the air of the meatus. The fact that the cartilage of the auricle is cut up by many fissures, and has only one narrow point of connection with that of the meatus, favours this latter view. It may further be remarked that some at least of the forms of the auricles are unquestionably designed to impart an appropriate ornamental character to these necessary appendages of the head; and the fitness, in this particular, of the human ears to the human head, is rendered very plain by a comparison of the fitness of animals' ears to the forms of their heads respectively. Though the *conducting* power of the walls of the auricle and meatus for atmospheric sound-waves is insignificant, and perhaps specially provided against in the ordinary condition, yet when the meatus is closed externally with the tip of the finger or otherwise, the sounds then caused by scratching the auricle and especially the tragus, or by holding a watch against them, are very loud. They are, in fact, increased, through the intervention of the principle of resonance; for the meatus being closed, constitutes a resonant chamber, the reciprocal vibrations set up in the air of which act on the membrana tympani, and so intensify the original sound. All *head sounds*, such, namely, as pass through the teeth or cranial bones, are also rendered very much louder in a similar way.

The *membrane of the drum*, which may to a certain extent be thrown into vibrations through the bony ring in which it is set, is chiefly intended to be influenced by atmospheric sound-waves received through the meatus; and its slanting position at the bottom of that tube is probably intended to adapt it to receive at a due angle, or perhaps perpendicularly, the vibratory impulses in question. The action of these on the membrana tympani may be imitated experimentally, by sounding a fiddle-bow near the dissected tympanum of an ox, or near an artificial tympanum with a drumhead of parchment, paper, or membrane, upon which some fine powder has been spread,—when certain movements in the particles of powder will indicate the existence of vibrations in the membranous structure. But, as is the case with stretched membranes generally, although a proportion of all sound-waves, whether irregular or regular, within certain limits, will act on the membrana tympani, yet some further provision is necessary to enable it accurately to vibrate in unison with *definite tones;* and this is secured by the effect of the tympanic muscles and ossicles in tightening or relaxing that membrane. To collect for record by the auditory sense any regular or musical tone, this membrane must of necessity vibrate to or in unison with that tone *reciprocally;* and for this purpose it must be as truly tuned to that note as if it were the cord of a stringed instrument. To do this for a wide range of tones, its state of tension must continually vary; and we know that for grave or low sounds it must be relaxed, and for high ones rendered tense. If, indeed, it be tightened in one's own ear, by forcing air voluntarily into the tympanum, through the Eustachian tube, grave sounds are rendered less audible, whilst high ones are not affected. The same thing takes place on first descending in a diving-bell. In all probability the necessarily varied condition of this membrane as to tension is duly regulated by reflex nervous action. A large tympanic membrane will more easily reciprocate grave tones, and *vice versâ;* and there exists a sort of correspondence between its size in different animals, and the tones of their respective voices.

The vibrations set up in the comparatively large collecting area of the membrana tympani are propagated chiefly, most readily, and indeed in a concentrated manner, through the little chain of solid ossicles, and so past the base of the stapes, fitted as it is in so peculiar a way by its surrounding ligament into the oval fenestra, to the fluid or perilymph of the labyrinth. By some it has been contended that the little tympanic bones are solely employed as levers in regulating the tension of the three membranes of the drum, viz., the membrana tympani, the membrane closing, with the stapes, the oval fenestra, and also, through the medium of the perilymph in the cochlea, that shutting in the round fenestra. According to this view, the sonorous vibrations produced in the membrane of the drum are not conducted through the ossicles, but are supposed to be propagated entirely through the air in the tympanum, either to the membrane of the round fenestra, or to the inner wall of the tympanum generally, and so to the parts within the labyrinth. But the greater conducting power of these little bones in comparison with air, their almost complete isolation in the tympanic atmosphere, and their special connection with the expanded membrane of the drum, on the one hand, and with the principal entrance to the labyrinth, on the other, would seem to indicate that they form the principal path of the vibratory impulses,—and, indeed, practically, *the* path by which we recognize all regular sounds whatsoever. It is difficult to conceive how sounds coming through two such different paths should not interfere with and confuse each other. One or other of them must, then, be the special path; and whilst the combination of membranes and solid materials in the case of the tympanic apparatus is elaborately constructed, most completely in accord with those principles of the conduction of sound which have been previously explained, there appear, on the other hand, to be contrivances in regard to the tympanic chamber itself specially calculated to impair the conducting properties of its contained air. The free communication of the tympanum with the mastoid cells and the Eustachian tube, and the moist character of the inner surface of all three of these parts, must tend to damp and deaden all sonorous undulations set up in the air within them, however produced. The moist inner surface of the membrane of the tympanum is especially adverse to the communication of its own vibrations to the tympanic atmosphere, and likewise to the reception of any such as, striking on its inner surface, might, if received upon a dry surface, interfere with those which are necessarily received on its outer surface. The moist mucous tissue investing the tympanic bones also renders them particularly bad conductors of vibrations to or from the tympanic atmosphere, thus securing them against loss one way, and interference in another. It must also be remembered that the fenestra rotunda, the supposed path to the labyrinth of any air-conducted vibrations, is, in comparison with the oval fenestra, small, retired in position, and in only limited connection with the labyrinthic cavities. It is certain that, had the tympanum been a perfectly-closed chamber, with a dry interior, it would have possessed good reciprocating properties; but in its actual state it would seem as if every possible precaution were taken to provide against such a contingency. Finally, the tympanum evidently acts as an air-chamber, which, as a bad conductor of heat, interposed between the labyrinth and the external air, preserves the temperature of the delicate parts within the former at a uniform standard, and prevents the possibility of mischief from extremes of temperature without.

The Eustachian tube, communicating with the external air through the pharynx, serves the important office of insuring an equal atmospheric pressure on the two sides of the membrane of the drum, and thus facilitates its vibrating under very feeble impulses. If, however, the tympanic cavity were closed at all sides, vibrations in its little drumhead would still take place, but the Eustachian outlet guarantees their freedom, protects the membrana tympani against the effects of external atmospheric shocks, and also permits, without undue tension and danger of laceration, the requisite changes of drawing-in and resilience of the membrane, through the action of its little ossicles and their muscles—nice adjustments which would be interrupted if the tympanum were hermetically closed. Besides this, the Eustachian tube serves as a conduit for the escape of the fluids secreted in the tympanum and mastoid cells, which, though necessary to the functions of those parts, would, if accumulated in excess, certainly interfere with them. Not that the Eustachian tubes on each side are habitually *open* at their pharyngeal ends, for this it appears only happens in swallowing, and yawning, or under a voluntary effort which one can make by forcing air into them when the mouth and nostrils are closed. But they are, or should be, always *pervious*, and this is sufficient to secure the objects for which they are intended. Practically, when they are wholly obstructed, by mucous, by swelling of the mucous membrane at the orifice, by the pressure of enlarged tonsils or of tumours, more or less deafness to sounds coming through the air is the result. The notion that the Eustachian tubes convey one's own voice to the ears is incorrect.

Arrived at the perilymph of the labyrinth, and thus destined, in the case of all sounds, and indeed as a universal rule in all animals whatsoever, to pass through a fluid medium before impinging on the terminal filaments of the auditory nerve, the sonorous vibrations coming from the tympanum travel through this fluid partly to the membranous utricle, saccule and semicircular canals, so as to reach the extremities of the nerves spread out in their interior or lying amidst the otoconia in the endolymph, and partly along the vestibular scala of the cochlea, pulsating over its denticulate lamina and radiating nerves up to its very summit, and then back down the tympanic scala to the membrane of the round fenestra. By its access to the tympanum, this membrane may act as a spring to save the delicate cochlear apparatus from too sharp undulations; or it may facilitate the due adjustment of the contents of the labyrinth as to tension, to suit different sounds, mainly effected through the action of the base of the stapes at the fenestra ovalis. On the theory that the air in the tympanum is the chief path of sonorous impulses, the course of them to the labyrinth would be through the membrane of the round fenestra, up the tympanic, and down the vestibular cochlea. But, as before said, here also the existence of two paths for the same impulses is unlikely, and this one appears not so direct and easy a one as that through the oval fenestra. The graduated lengths of the rods of the denticulate lamina of the cochlea have naturally suggested the possibility of their being connected with the reception of sounds of different intensity, the sonorous undulations of which are themselves of various lengths: but at present this is only a conjecture; and indeed, though well calculated to astonish us, as evidence of Creative power, the many parts found in that intricate anatomical *maze*, appropriately called the labyrinth, have hitherto baffled all inquirers who have endeavoured to determine their respective uses. Enough concerning the entire auditory apparatus has, however, been discovered to show a more refined adaptation of organic structures to physical uses than even that already described as presented by the organ of voice.

From what has been said concerning the physical causes of sounds and their appreciation by the ear, it is evident that sound, as such, has no existence in nature, and indeed cannot exist, independently of a sense of hearing. Without such a living faculty, all nature would be silent. What really does happen, physically speaking, is this; that there constantly occur as the result of concussion, friction, or other evidences of force, certain disturbances of state in elastic bodies, which disturbances have been determined, by a process of observation and intellectual analysis, to be delicate undulations or tremors capable of regular propagation in all directions. Some matter to be thrown into tremor is however indispensable; for sounds can neither be produced in, nor be propagated through, a vacuum, as is proved by the silence of a bell struck under the receiver of an air-pump.

It has also been shown that these tremors must succeed each other with a certain rapidity, or they do not give rise to the sensation we call sound; and, on the other hand, they must not exceed a certain rate, or they are equally inaudible to us. Fewer than 8 and more than 24,000 tremors per second produce no effect on the human ear; and doubtless beyond either extreme, undulations of a similar kind are constantly occurring which pass by us *unheard*. So too of course there may be tastes, odours, and sights imperceptible to us.

Irregular sonorous tremors produce *noises;* whilst a succession of uniform undulations give rise in our ears to regular or *musical tones*. The slower undulations produce low or *grave* tones, the quicker ones sharp or *high*-pitched tones. The notes of a bassoon and of a fife, the roar of a lion and the mewing of a cat, the voices of a man and of a child, illustrate this difference of *pitch*. The gravest note capable of being distinctly appreciated must be the fundamental note of the membrana tympani in its most relaxed state, for no lower one can cause reciprocal vibrations in it. It has been computed that the wings of a gnat move 15,000 times in a second to produce the high-pitched humming noise which these creatures make. The chirp of the field-cricket is a still higher note; and there are many persons who cannot distinguish this and other like sounds. Other persons again are deaf to very grave sounds.

All sounds, whether grave or high, are propagated through any given medium at the same rate; otherwise, for example, the different sounds from an orchestra would reach us at different times, and completely destroy the intended effect. Through air sounds travel about 1,125 feet in a second, through water about 4,700 feet in a second, and through solids, such as woods and metallic bodies, from 10 to 15 times as rapidly as through air. The rate of sound through air has been measured by noting the lapse of time between seeing the flash of a distant gun and hearing the report,—light travelling so much faster than sound. In the same way, it may be calculated that for every five seconds intervening between a flash of lightning and the commencement of the consequent thunder-clap, rather more than a mile of distance exists between us and the discharging cloud. The conducting power of air for sound increases with its density, and diminishes according to its rarefaction, until, as already mentioned, in a vacuum there is no sound conducted at all. Hence, at high elevations above the sea, the voice appears weak, whilst it is louder in a diving-bell. Cold, by increasing the density of air, and stillness, for obvious reasons, favour this conducting power. Dense gases and vapours conduct better than light ones, so that hydrogen gas, the lightest body known, is the worst conductor.

The *intensity* or *loudness* of a sound depends on the extent and force of the undulatory movements which produce it; and as these spread in all directions equally, the intensity diminishes as the square of the distance, so that at double the distance it decreases to one-fourth, and at four times the distance to a sixteenth of its original loudness. The causes of *timbre* or *quality* are not well understood; but they seem to be due to the physical character or structure of the particular elastic body set in vibration, which modifies in some way the characters of the atmospheric sound-waves.

The basis of *harmonic sounds*, and therefore of all *music*, depends on a law,—to which our ears and our auditory sensorial centres must be strictly adapted,—according to which those sound-waves whose rates of undulation correspond, or are in certain definite numerical proportion to each other, are more or less agreeable to the ear, whilst those which do not, are disagreeable when heard together or in succession. The former are called *concords;* the latter produce *discords*. Tones whose undulations exactly correspond, are the same *notes*, whether produced by a violin, a flute, or a piano. When the undulations of a given note are just double those of another, we have the *octave* of that note, or the most perfect concord. Octaves, indeed, are the same *notes*, but higher or lower in the scale. The intermediate notes of the octave are produced by undulations whose rates have a more and more complex ratio to that of the vibrations of the fundamental tone.

Unlike the tongue and nose, which, besides their sensory offices, serve, the one in speaking and eating, and the other in breathing and voice, the ear is a special organ devoted to only one purpose. The sphere of its observation is also very special, and in some respects more so even than that of the eye, inasmuch as it gives access to one peculiar sort of knowledge wholly unattainable in any other way, affording us information and supplying us with materials for research and reason otherwise beyond our reach, and opening up to us a vast field of enjoyment, and the means of penetrating to the secrets of a quite invisible world.

By means of this sense,—especially as exercised by the aid of two ears, a consequence of the general law of bilateral development,—we judge of the situation, distance, and motion of remote and unseen bodies as well as of near and visible ones. It does not minister, like the senses of taste and smell, to the grosser pleasures of the appetite; and it is not the source of such wide and perfect knowledge as the eye; but it is the sense through which all nature *speaks* to us in her manifold voices, excites within us the higher emotions, and feeds the sense of harmony, which is a mental quality. By a play of the fancy, it suggested to one of the loftiest of human minds that memorable and noble idea of the "music of the spheres," and has given occasion to the metaphor, almost inspired, by which we acknowledge the "whisperings" of an internal conscience.

In its necessary relations to voice, hearing becomes the great social sense, the chief inlet of intercommunication with others, and the interpreter of our mutual wants, wishes, and thoughts. It not only tells us of the proximity of friends, and warns us of the approach of foes, but it also urges us to fly, at the cry for help, to the succour of the distressed. Its loss from birth is even a greater deprivation than that of sight, and the born deaf, being dumb, are decidedly less sociable and happy than the blind.

Hearing is likewise the chief mode of communication between animals and ourselves; for by it we soon learn rightly to associate the cries of animals with the true expressional meaning. In a lower sense, it is also a guardian against bodily evil, enabling us to frustrate the petty annoyances of the gnat, to anticipate the approach of beasts of prey, and to avoid the deadly danger of the rattlesnake.

It is a sense strangely liable to be deceived, as witness the feats of ventriloquists, who, by imitating particular sounds as they would be heard at different distances, and by suggesting to the mind the idea of special direction, contrive to make the hearer suppose all imaginable impossibilities. By cultivation, hearing becomes, like all the senses, very acute,—as in the Indian who listens on the ground for the distant foot-fall of his enemy or his prey. Temporarily in absolute darkness, and permanently in blindness, it generally becomes more acute. Its absence at birth, as necessarily implying dumbness, has already been alluded to.

In the world of unseen harmonies, the sense of hearing, more or less successfully appealed to, by genius seizing the true associations of sounds with ideas, and by talent exercising itself in a musical art, is made to move us gently with the pastoral ditty, to excite our pity or desire, to stir up a national, patriotic, or martial spirit, to celebrate a victory, to subdue us with devotional melodies, or to overwhelm us with those marvellous creations of the human soul and mind, the grand and majestic combinations of the oratorio. And not the least marvellous feature of these various musical performances is the fact, so contrasted with the fixity of the results of the arts of painting and sculpture, that they are quite evanescent,—as transient, indeed, as the atmospheric sound-waves which produce them. They can, however, by way of compensation, be endlessly repeated, still again to die away;

and in accomplishing this, man has to educate his inventive and his executive powers, in the manufacture and use of musical instruments, to a far greater extent and perfection than is required for the purposes of either sculpture or painting.

The faculty of musical perception, and, of course, the power of composition, are both mental; but it is not unlikely, in regard to the former, that the auditory apparatus of those who possess it in the highest degree is peculiarly perfect in its physical construction.

THE ORGANS OF SIGHT.

THE EYES AND THEIR APPENDAGES.

Figures 20 to 25.

The organs of sight consist essentially of the two globular bodies called the *eyeballs*, which are organic optical apparatuses, superadded to and containing the extremities of the optic nerves or nerves of sight.

The eyeballs, or globes of the eyes, are lodged, for the sake of protection, in the large bony cavities called the *eye-sockets*, or *orbits*, formed between the cranium and the face. These cavities, seen in diagram No. 1, figs. 1 and 2, and mentioned at pp. 4 and 5, are pyramidal hollows, having their apices directed backwards and inwards, so that their axes are divergent anteriorly, and convergent behind. The outer margin of each falls back, so as to allow a greater range of vision for the corresponding eye on that side. At the bottom of each socket are large openings, round and long, for the entrance into the orbit of the optic nerve, and of the sympathetic, sensory, and motor nerves of the eyeball and its muscles, and also for the passage of bloodvessels and lymphatics. Besides the eyeball, the optic and other nerves, the muscles, and vessels, the orbits contain a quantity of fat, on which the eyeball rests, as on a soft elastic bed, and, lastly, the *lacrymal gland* which secretes the tears.

Above, the orbits are surmounted by the *eyebrows*, and in front they are closed in by the *eyelids*, which, according as they are open or shut, occupy more or less space in the orbit, and partially or completely conceal the eyeballs. The *lacrymal apparatus*, which includes not only the gland but certain canals by which the tears and other fluids are conveyed away, after having moistened the surfaces of the eyeball and eyelids, is also situated in or near the orbit. The structure and offices of these several parts, which are called the *appendages of the eye*, also *tutamina oculi*, or defences of the eye, present many points of considerable interest.

The Appendages of the Eye.

Figures 20 and 25.

The *eyebrows* are thick musculo-cutaneous ridges containing some fat, and studded with stiff hairs set obliquely outwards and overlapping each other from above and below towards the middle line of the ridge. The muscular fibres in them belong partly to the *frontal* muscle, marked 1, in diagram No. 2, fig. 1, partly to the *orbicular* muscle of the eyelids, 3, but chiefly to another muscle, more deeply seated, called from its action the *corrugator of the eyebrow*. By means of these muscles, the eyebrows may be either raised, in which action we make horizontal wrinkles on the forehead, or lowered, or more or less corrugated or drawn together, so as to produce vertical wrinkles as in frowning.

Properly speaking, distinct eyebrows are almost peculiar to man. They serve habitually, in the erect position, to protect the eyes against any excess of light or glare coming from above; for by being raised or lowered they can greatly influence the quantity of light so reaching the eye. They also protect the eyes against falling rain, snow, or dirt, and direct the streams of the sweat of our foreheads away from the eyes to the sides of the nose and cheeks. They add to the beauty of the face, and especially in the female occasionally present a singularly perfect arched form. To all faces they give character; and by their slow or rapid movements, and their great varieties of position, impart the appearance of vivacity, thought, or astonishment, and some of the gloomiest expressions to the human countenance.

The *eyelids*, or palpebræ, are, as their name implies, really movable *lids* or *covers* to the eyeballs. The upper one is much the larger and more movable of the two. Examined anatomically, they are found to consist outside of a thin skin, so loosely connected as to allow of their easy movement, and free from fat even in the stoutest people, or their motion would be obstructed, and indeed the opening between them closed up. The looseness of the skin also favours its sudden swelling from inflammation as in erysipelas, or from the effusion of blood as in the case of a "black eye," as it is called, caused by any accidental contusion or gained as the reward of fighting. Next to the skin is a thin layer of muscular fibres belonging to the orbicular muscle. Beneath these are two thin plates of soft fibro-cartilage, one semi-lunar in the upper eyelid, and one a mere narrow strip in the lower lid. These are the *tarsal cartilages*, or *tarsi*, which form the framework of the eyelids, give shape, definition, firmness, and flexibility to their marginal portions, enable them to fit accurately to the eyeball, and diffuse the pressure exerted by the orbicular muscle evenly over that part. In the substance of these cartilages are lodged some peculiar glands, called the *Meibomian glands*. The cartilages are held in position by broad membranes attached to their deep edges on the one hand, and to the periosteum of the rim of the orbit on the other, being especially strengthened on each side, where they serve to tie the ends of the cartilages to the bone, and form a sort of hinges on which they move in the opening and shutting of the lids. The bands from the inner ends of the cartilages join a short, strong, horizontal, tendinous slip, called the *tendon of the eyelids*, which may easily be demonstrated during life by stretching the eyelids outwards: this serves to fix the cartilages most particularly in that direction, and also gives origin to many of the fibres of the orbicular muscle which draw on and close the lids. Beneath this tendon is a forked set of muscular fibres, which extend from the inner side of the orbit to the tips of the cartilages, and under the name of the *tensor tarsi* muscle, help to keep the cartilages in constant contact with the eyeball, in the different movements of the parts. Lastly, on the internal surface of the lids there is a layer of mucous membrane, which is continuous with the skin at the free margins of the eyelids, is also prolonged into sundry gland-ducts and other canals to be presently described, and, moreover, is reflected all round at a certain distance from the margin of the lids on to the eyeball, so as to attach these two parts together, and is hence named the *conjunctiva*. About the anterior third of the surface of the eyeball is thus covered by the conjunctiva, which, in the very front of the translucent part of the eyeball, is exceedingly thin, and quite colourless and transparent. The part which covers the white portion of the eyeball is thicker, but is still thin and transparent, has no papillæ on it, and is not very sensitive. That part, however, which lines the eyelids is much thicker, very soft, of a pinkish colour, and provided with numerous closely-set papillæ, and is endowed with exquisite sensibility, derived from branches of the fifth cranial nerve. This is instantly experienced, when anything gets into the eye, as it is called, which merely means that it has lodged in the sort of circular groove or cul-de-sac between the eyelids and eyeball. A foreign body thus lodged causes most pain when it is between the tarsal cartilages and the eyeball, for there it is subject to friction and pressure between more resisting surfaces than are found at the very deep parts of the conjunctival cul-de-sac, which extends beyond the cartilages, is loose and folded to admit of the movements of the eyeball, and is deepest opposite the middle of the upper and more movable eyelid. It can easily be understood that the sensori-motor contraction of the orbicular muscle, irritated and excited by the foreign body, increases the mischief unless its spasmodic efforts be controlled by the will. The part of the conjunctiva which immediately lines the cartilages, is neatly and firmly adherent to them, or else it would be liable to be thrown into puckers, and so cause much distress; as it is, it greatly facilitates their gliding movement. The epithelium of the conjunctiva is of the squamous kind, and is composed of several layers of flattened cells. (See diagram No. 9, fig. 80.) It is probably covered also with a proper mucous secretion, though doubtless, the slow secretion of tears and of the Meibomian fluid chiefly serve to keep it moist.

The *Meibomian glands*, already mentioned, occupy little channels purposely hollowed out for them in the soft substance of the tarsal cartilages; though plainly seen on the ocular surface of the lids, they do not project so as to impede the movement of these upon the eyes, or cause any pain. They consist of a series of long tubes or ducts placed nearly parallel to each other, and perpendicularly to the margins of the lids, where they open by a row of minute orifices, as shown in fig. 20, and as may readily be seen in the living eye, by aid of a pocket-lens. At their further ends these ducts are closed, and along their sides they communicate with a crowd of closely-packed little pouches or crypts, which are the secreting follicles of these modified and complex *sebaceous glands*. Their form and arrangement are represented in fig. 25, which shows a portion of the upper lid, with its eyelashes, and five of the compound Meibomian follicles, *b*, with their orifices on the margin of the lid, *a*. There are about 15 to 20 of these glands in the lower lid, where they are very short, and about 30 in the upper one. They consist of a membranous wall, lined with a glandular epithelium, continuous with, but differing from, that of the conjunctiva, and they pour out a sebaceous or unctuous fluid, which lubricates the margin of the lids, guards them against the action of the tears, prevents them from sticking together in sleep, and is doubtless distributed also on the opposed surfaces of the eyelids and eyeball.

In the upper eyelid there is found an additional constituent, not represented in the lower lid. This is the thin, or expanded anterior end of a small muscle, called, from its office, the *levator muscle of the upper eyelid*, *levator palpebræ*, which arises by a narrow point from the bottom of the orbit, and passing forwards immediately beneath the periosteum and above the eyeball and its muscles, is attached to the upper tarsal cartilage by its expanded tendon. It serves to pull back the upper eyelid, and so to uncover the eyeball.

The interval between the opened eyelids, through which, as shown in fig. 20, a part only of the eyeball is visible, is called the *palpebral fissure.* The margins of the lids, which of course bound this fissure, present flat or bevelled surfaces, about a line in width at their widest part. That edge of these surfaces which is next to the eyeball is particularly sharply defined, so as to sweep cleanly over it; along the middle of the surfaces are the openings of the Meibomian glands; whilst the outer edge next to the skin is rounded, and carries the eyelashes.

The *eyelashes,* or *cilia,* consist of two, and opposite the middle of the eyelid, of three rows of finely-curved hairs,—those of the upper lid being more numerous, thicker, and longer than those of the lower lid. They serve to exclude excessive light, especially the long lashes above; and they also guard the eye against the entrance of insects or foreign bodies, acting, through the sensitive nerves at their roots, as indirectly sensitive and protective fringes in advance of the eyelids themselves. The upper and lower lashes curve in opposite directions, so that they can meet and separate again without entanglement of their ends; and they also in this way sooner intercept the light or hurtful foreign bodies.

The outer and inner corners of the palpebral fissure are called the *canthi.* At the outer canthus, the bevelled margins of the eyelids meet at an acute angle; but on being traced towards the inner canthus, they suddenly change their character and direction, opposite the inner ends of the tarsal cartilages, where they leave the eyeball and embrace with their now rounded margins a little recess called the *lacus lacrymalis,* or lacrymal lake, because the tears tend towards and collect in it. On the inner side of this recess is placed a soft, red, fleshy-looking eminence, called the *caruncle,* from *caro,* flesh, which is composed of conjunctival mucous membrane, studded with a few very fine hairs, and including a congeries of sebaceous follicles, which secrete an unctuous fluid to lubricate the surrounding parts. Between the caruncle and the eyeball is a thin semilunar fold of the mucous membrane, having its free concave edge turned towards the eyeball. This is the *plica semilunaris:* it is stretched when the ball of the eye is turned outwards; and it is regarded as the corresponding part to the *membrana nictitans, nictitating membrane,* from *nicto,* to wink, or *haw* of the horse and the mammalia generally, and of the *third eyelid* of birds.

Upon the extreme inner end of the bevelled margins of the eyelids, where these change into the rounded borders of the lacrymal lake, and turned inwards and backwards towards that recess, are two little conical eminences, one for each eyelid, named the *lacrymal papillæ,* in the centre of each of which exists an opening, visible to the naked eye, called the *lacrymal punctum* or point, which brings us to the consideration of the *lacrymal apparatus* generally.

This consists, in the first place, of the *lacrymal gland,*—or *tear-gland,*—a small oblong lobulated body, the shape, position, and size of which are indicated by the dotted outline, *g,* seen at the upper and outer side of the eye in fig. 20, and also at *g,* fig. 21. It is lodged in a slight depression in the bony wall of the orbit, between it and the general mass of the eyeball, reaching forwards to the upper lid, to which a part of it is fixed. Its ultimate lobules, composed, like the salivary glands, of branched tubes ending in vesicles, join together to form lobes, from which finally about 6 to 12 ducts proceed to the conjunctival surface of the upper eyelid, just above the *outer* canthus, where they open, and there pour out the tears secreted by the gland over the free surface of the eyeball. The tears themselves are saline and distinctly alkaline; they contain a very little animal matter, which appears like mucus. When secreted abundantly, they are probably more watery than in the usual condition of flow.

The *lacrymal points*, or *puncta*, already mentioned, lead to that part of the lacrymal apparatus next to be described, which is designed to carry away the redundant tears and other secretions down into the nose, after they have passed over the eyeball and eyelids. It includes the two lacrymal canals, the lacrymal sac, and the nasal duct. The *lacrymal canals* are two short tubes, about $\frac{1}{30}$th of an inch in their internal diameter, leading from the puncta, at first upwards or downwards and then inwards, one above and one below the lacrymal lake at the inner canthus, as shown by the dotted outlines, *c c*, in fig. 20, and ending either separately or conjointly in a large membranous bag, *s*, closed above but open below, which is called the *lacrymal sac*. This sac, lodged in the *lacrymal groove* in the margin of the orbit (mentioned under No. 1, figs. 1 and 2, pp. 4, 5, and also partly shown at *l*, in fig. 14 of the present diagram), ends below in a narrower tube, called the *nasal duct*, *d*, which opens at its lower end, usually by a partly-valved orifice, into the corresponding nasal cavity, under cover of the inferior turbinated bone. There is thus established a channel of communication from the conjunctival surfaces to the interior of the nose, along which the mucous, lacrymal, Meibomian, and caruncular secretions may flow. The mucous membrane lining these continuous parts, is laminated and destitute of cilia in the lacrymal canals and upper parts of the lacrymal sac, whilst in the lower part of that sac and in the nasal duct it is ciliated, like the adjoining nasal mucous membrane. The lacrymal canals and sac have a fibro-elastic coat outside their mucous lining, and the upper part of the sac itself, besides being covered by the skin at the side of the root of the nose, is crossed by the horizontal tendon of the eyelids, and also by the internal fibres of the orbicular muscle of the lids; besides this, the little tensor tarsi muscle passes beneath and to the inner side of the sac, and then bifurcates to spread along the two lacrymal canals, as far as their puncta, to reach the tarsal cartilages.

The eyelids and lacrymal apparatus present as remarkable a piece of design as any to be found in the human body, having for their object in many ways the protection, preservation, and perfect performance of the most delicate of our organs of sense.

During sleep, the eyelids form neatly-fitted shutters, for the exclusion of light, insects, dust, and other foreign bodies. The first of these purposes especially is both simply and effectually carried out by the upper eyelid moving down over the whole transparent part of the eyeball, whilst the lower lid moves up only a little way to meet it; for in this manner the cleft between the edges of the two lids is not in the line of vision. The closure of the lids during sleep is due to a continuous reflex action of the palpebral part of the orbicular muscle, particularly of the fibres nearest the margin of the eyelids. As already mentioned, the edges of the lids are prevented from sticking together owing to the drying up of the secretions, by the unctuous character of the Meibomian fluid.

In fainting and death, the upper eyelids fall, but so as only partially to cover the eyeballs; and they are not met by the ascent of the lower lids.

In the waking state, the action of the palpebral portion of the orbicular muscle is suspended, the lower eyelid descends a little by virtue of the elasticity of its cutaneous and membranous tissues, whilst, by means of a volitional impulse, the upper eyelid is drawn up, like the visor of a helmet, from the front of the eyeball back into the orbit, by its proper levator muscle. The extent to which the eyelids open varies according to the will, and depends mainly, but not entirely, on the position of the upper lid. In looking down, this lid is depressed; in looking up, it retires almost completely beneath the over-arching brow; it follows strictly the downward movement of the eyeball, so that it is impossible for the levator muscle to raise it when the eyeball is directed on the ground, though it is easy to depress it or close it—by aid of the orbicular muscle—when the eyeball is raised. In a strong light, the lids are brought nearer together, in order, with the assistance of the eyelashes to moderate, by a partial exclusion, the action of the light on the eye. In looking at very near objects, and habitually by short-sighted persons, the same thing is done, for optical reasons to be hereafter alluded to. Under the voluntary impulse, also, the lids may be opened wide, as in a feeble light, and in looking at distant objects; they may be lightly closed, as in meditation; or rapidly shut and opened, as in fun; or tightly compressed together, as in making certain strong efforts, or for the purpose of excluding water, smoke, or dust driven by the wind. This forcible compression engages the whole of the orbicular muscle, not merely its palpebral portion; and in it both lids, but especially the lower one, distinctly travel in towards the inner canthus, probably by the action of the little tensor tarsi muscle as well as by the orbicularis. It is this act which produces the wrinkles about the outer corners of the eyes, called *crow's feet*, seen in persons much exposed to weather and light, and as the result of the absorption of fat in old people. In taking aim with firearms, or in looking through a telescope, the lids of one eye only are thus voluntarily compressed, and very firmly too, or they would open by a consensual action with those of the other eye, for the lids of both eyes usually act together.

Under the influence of the emotions, the lids may be nearly or quite closed, as in laughter; or wide apart, as in astonishment and fright; or the upper one may droop, as from humility, modesty, shame, or contrition.

But the most frequent use of the eyelids is in that rapid shutting and re-opening of these movable covers to the eye, which constitute the act of *winking*,—an act of a purely reflex character, usually almost if not entirely unaccompanied by sensation or consciousness. The necessity for winking is shown by the great effort required to restrain it even for a short time, and by the impossibility of doing so for a continuance. First discomfort, then congestion of the conjunctiva, and then a profuse watering of the eye follow any attempt at stopping this necessary act. It is an obscure sense of discomfort, not usually noticed by the consciousness, that excites this movement, the objects of which are periodically to cleanse the exposed part of the eyeball, to moisten and lubricate it with the secretions from the neighbouring glands, and probably in this way to aid in the preservation of the polish and translucency of the epithelial layer on the transparent portion of the globe. At the same time it carries towards the inner canthus all foreign bodies, and directs the residual secretions towards the lacrymal puncta. Finally it allows a brief but periodical rest to the levator muscle of the upper eyelid.

In winking, both lids move, but the upper one much the more extensively. Moreover, they do not come in contact all along their margins at the same instant of time, but meet first at the outer canthus and then rapidly inwards as far as the lacrymal papillæ on which the lacrymal puncta are situated. By this sweeping movement, all foreign bodies are carried to the lacrymal lake, where it is well known they accumulate, in preference to the outer canthus. By this means also, the lacrymal secretion poured out at the upper and outer part of the eyeball, the mucous secretion proper to the conjunctiva, and the sebaceous Meibomian fluid, are carried swiftly in an oblique direction towards the mouths of the puncta, where the more fluid parts are drained away into the lacrymal canals, and thence down the lacrymal sac and nasal duct into the nose, which they assist in keeping comfortably moist.

The diffusion of the tears and other secretions over the lids and ball of the eye, and their descent to the lacrymal lake, are partly due to gravitation and to capillary attraction; and so is their subsequent course along the lacrymal canals, lacrymal sac, and nasal duct. In the last three passages, they are probably sucked in and urged on by the action of the tensor tarsi muscle on the canals, and of the orbicular muscle on the sac. The tensor tarsi is thought also to turn the puncta, which are kept well lubricated by the caruncular secretion, inwards towards the lacrymal lake.

It has also been said, though the truth of the statement is denied by some, that, owing to the bevelling of the margins of the eyelids, when these latter meet momentarily as in winking, or persistently during sleep, there is a narrow three-sided channel formed between them and the anterior surface of the eyeball, along which the secretions flow directly to the puncta. This is supposed especially to be the mode in which the tears pass away during sleep. The greasy nature of the Meibomian secretion may perhaps assist in this latter condition to make the lids fit or cling more accurately, and in this, as well as in the open state of the eyelids, it may exercise a sort of repellent action, which prevents the tears, when secreted in their ordinary quantity, from running over the margin of the lower lid.

The continuousness of the lacrymal secretion is shown by the fact that when from injury or disease any obstruction exists in the canals, sac, or duct, the tears distil down the cheek, and the corresponding nasal cavity becomes uncomfortably dry. The formation and discharge of the tears are based indeed on the system of "constant supply;" the lacrymal passages affords an example of the most perfect "drainage," and the apparently superfluous waters are subsequently "utilized" in the nose. This little system of irrigation, though aided by special contrivances, is carried on in concurrence with gravity, and when there is an overflow of tears, these chase each other first from the lacrymal lake, and often from the lower lid generally.

In many cases, winking is a sensori-motor reflex act, as when an insect or some foreign mechanical or chemical irritant actually enters the eye, and excites the nerves of the sensitive conjunctiva, or communicates some impression of contact to the nerves at the roots of the eyelashes. In such cases, there also takes place a deluge of tears, secreted at a moment's notice,—for there is no lacrymal reservoir, like the gall-bladder for the bile,—to wash away the offending body, and relieve the irritation produced in the vessels of the part.

Irritation of the nasal mucous membrane, which is, like the conjunctiva, supplied by the fifth nerve, also produces a flow of tears, which, passing rapidly down the lacrymal passages, flood the interior of the nose: this is exemplified in snuff-taking or sniffing smelling-salts or mustard. Pricking the skin about the eyelids will also excite a flow of tears, through the agency of the fifth nerve; and so even will a very strong light, or anything which fatigues the eye, either through the action of the optic nerve, or through the branches of the fifth which go to the eyeball.

In certain emotions, a prodigious quantity of tears will sometimes flow. In deep grief they occasionally refuse for a time to do so; but when they do come, it is with the greatest relief to the pent-up feelings and overcharged emotional nervous centres.

Winking to protect the eyeball is sometimes a voluntary act, or at any rate is excited only through the optic nerve, as when we *see* a fly or a particle of dust, or any larger body coming towards the eye, and we close the lids before it touches them.

Finally, the interesting evidences of design exhibited in the mechanism and actions of the eyelids and lacrymal apparatus, varied as these are in reference to particular ends, become not less striking when we reflect how wonderfully they are all adjusted through the nervous system,—the movements being executed through purely reflex, sensori-motor, or voluntary influence, and the activity of the secreting function being regulated by the conjoint operation of the sensory and sympathetic nerves.

The Eyeballs.

Figures 20 and 21.

Each *eyeball* is a strong globular membranous bag, having partly transparent and partly opaque walls, consisting of several coats, and containing within it, besides other structures, certain transparent colourless contents called *humours*, and the expanded extremity of the *optic nerve*.

In front, the eyeball is free, and partially visible between the opened eyelids. The surface thus exposed, as shown in fig. 20, includes the whole of its transparent walls, corresponding with the *coloured* part of the eye, but only a very small portion of the opaque walls, constituting what is called the "*white* of the eye." The differences between so-called large and small eyes, and the peculiarities of round, long, or oblique eyes, like those of the Chinese, depend on individual or national peculiarities in the size, shape, and position of the aperture between the eyelids, and not on differences in the globe of the eye itself, the variations in size of which are comparatively small. The relative prominence of the eyeball is due partly to its size, but much more to some deviation from the ordinary proportion between the depth of the orbit and the bulk of its contents.

Behind, the eyeball is attached, as if upon a stalk, to the optic nerve, fig. 20, *n*, the fibres of which enter it and spread out in its interior. Besides this, it is held in position by muscles, 1 to 4, which pass from the walls of the orbit, and embrace it on all sides. Filling up the otherwise unoccupied places of the orbital cavity, and especially accumulated in the interval between the ocular muscles and the optic nerve immediately at the back of the eyeball, is a quantity of very soft fat, which supports the ball, with its blood-vessels and nerves, when it is at rest, and acts as a sort of cushion or bed, on which it is moved by its muscles in various directions. When the eyeballs are at rest, or are moving together over the field of vision, lines drawn through their centres from front to back, called their *antero-posterior axes*, are parallel.

When removed from the orbit, the eyeball is seen to correspond in shape to the larger portion of a sphere, *ss*, having a segment of a smaller sphere, *c*, affixed to it in front,—the former coinciding with its opaque, and the latter with its transparent membranous walls. In the adult, it measures from front to back about 1 inch; its width, usually believed to be rather less than the antero-posterior diameter, has been found by more recent measurements to be a trifle greater. The size of the eyeballs is usually proportioned to that of the body, so that they are on the whole smaller in women than in men; but they are relatively to the body somewhat larger in infants and children.

When an eyeball is laid open by cutting through its tough or membranous walls, its contents escape and its sides collapse. Supposing, however, an horizontal section could be made of one of the eyeballs, so that the parts retained their mutual relations to each other, they would present the appearance shown in the sectional plan of the *right* eye in fig. 21. The cut edges of its strong walls would then be seen, surrounding its softer transparent contents or humours. These walls would be seen to consist of three kinds of *coats*, as follows: first, proceeding from within outwards, there is a strong, *fibrous*, and somewhat elastic coat, the greater part of which is opaque and called the *sclerotic*, *s'*, whilst the smaller anterior part is transparent, and is named the *cornea*, *c'*. Within the sclerotic portion of this outer envelope is a tender, highly *vascular* coat, containing a quantity of black or brown *pigment*, named the *choroid coat*, *e*, the fore-part of which is developed into a set of radiating folds, called the *ciliary processes*, indicated by the lower line leading from *b;* and with which it is usual to associate an important set of muscular bundles called the *ciliary muscle*, indicated by the upper line leading from *b*, and a very remarkable vascular, membranous, and muscular structure, named the *iris*, *i*. Within the choroid, is the third tunic, called the *nervous coat*, which is composed essentially of the terminal expansion of the optic nerve *n'*, and is named *the retina*, *r*.

The transparent humours of the eye, contained within these coats, are also of three kinds; viz., first, the *vitreous humour*, *v*, a jelly-like mass, which fills the posterior and larger part of the globe of the eye, lying next in contact with the retina; secondly, the *crystalline lens*, *l*, a small but firm body, which lies imbedded in the anterior part of the vitreous humour; and thirdly, the *aqueous humour*, *a*, a thin watery fluid, which occupies the remaining space within the eyeball, between the front of the crystalline lens and the inner or posterior surface of the cornea.

The eyeball, then, is a globular chamber, into which the transparent cornea and humours allow light to penetrate (as indicated by the lines in fig. 21), quite to the back part and sides, where it impinges upon the retina or sensitive coat, and there, having been so conducted through the transparent part as to form definite images of external objects, produces its characteristic impressions, which being conveyed to the sensorium, excite those sensations of which we are conscious as belonging to sight.

To comprehend the mode in which this is accomplished, and the uses of the several structures, whether coats or humours, above enumerated, requires a detailed examination of each of those parts; before proceeding to which, however, it will be convenient to describe the optic nerve, the ocular muscles, the common sensory, motor, and sympathetic nerves, and the blood-vessels of the eyeball.

The Optic Nerves.

From the optic commissure, *oc*, fig. 21, formed at the base of the brain by the union of the right and left optic tracts *o*, *o'* (see p. 125), the optic nerves *n*, *n'*, diverge and enter the orbits, where each is inclosed in a firm protecting sheath, *h*, which also penetrates between, and invests the numerous funiculi, *f*, of which the nerve is composed. In passing forwards, the optic nerves diverge, like the axes of the orbits themselves, and reach the eyeballs about $\frac{1}{10}$th of an inch to the inner side of and a little below their antero-posterior axes, which, as already stated, are usually parallel. The point of attachment of the optic nerves to the eyeballs is anatomically convenient; but it also has important physiological results, to be hereafter noticed. In their course to the eyeballs, the optic nerves are slightly curved, probably so as more easily to yield a little in different directions in the rolling movements of the eyes. Arrived at the sclerotic coat of the eyeball, the sheath of each optic nerve, *h*, with its numerous internal partitions, blends with that coat, whilst the component bundles of nerve-fibres, *f*, pass on into the ball; hence, if the nerve be cut off close to the sclerotic, it seems as if its cords passed through a cluster of minute pores, forming the *lamina cribosa* of that coat, an arrangement calculated to support and protect the nerve-fibres from disturbance to their delicate functions during any movements of the eyes. At the same time, the investing coat of the eyeball is less weakened than if the nerve had passed through a single opening in it. Having thus perforated the sclerotic, *s*, the nerve, apparently diminished in calibre, owing to its losing its sheath, passes through a distinct hole in the choroid coat, *e*, and then expands into the retina, or nervous coat, *r*,—to be presently described.

The Muscles of the Eyeballs.

Surrounding the sort of soft pedicle formed by the optic nerve, are five of the *six ocular muscles*, which move the eyeball in different directions. Four of these six muscles are called *recti*, or *straight*, and the other two *oblique*,—from differences in their course to the eyeball.

The four *straight* muscles, fig. 21, named *superior*, 1, *inferior*, *external*, 2, and *internal*, 3, spring from the bottom of the orbit, *t*, around the entrance of the optic nerve, *n*, and pass forward to their destinations, upon the corresponding sides of the eyeball, where their anterior tendons pass over its middle, clasping it closely, and are inserted respectively into its upper, lower, outer and inner sides, a little way behind the margin of the cornea. Being attached in advance of the transverse diameter of the ball, the four straight muscles can roll it upon its optic pedicle and supporting cushion of fat, upwards, downwards, outwards or inwards, according to the muscle brought into action. Hence these muscles have been named respectively, *attollens*, *depressor*, *abductor*, and *abductor* oculi. When two adjoining recti muscles act together, an intermediate or oblique movement is impressed on the eyeball, so that by their separate or conjoint action the transparent inlet to the light can be directed to any point with great accuracy. If all four act together, it is thought by some that they may slightly retract the eye into the orbit; and it is also conjectured, that, by their united action, resisted by the oblique muscles and the parts behind the eyeball, they may compress and so alter its shape as to increase its antero-posterior diameter, and even render the cornea more prominent. In the state of rest, the eyeballs are kept in their parallel position by the elasticity of their surrounding connections,—their muscles acting only by their general tonicity. They are thus lightly and evenly held in balance, ready for any movement. When, however, any one muscle has an undue preponderance over its antagonist, the natural position of equilibrium is disturbed, and some kind of *squint* is the result. The commonest kind is an internal squint, towards the nose; it must depend either on great power in the internal rectus, or on some enfeeblement of the external one.

Of the two *oblique* muscles, one named the *superior*, 4, also springs from the bottom of the orbit, and passing forwards along the inner side of the levator-palpebræ muscle, is directed to the upper and inner corner of the margin of the orbit, where having become tendinous, it turns through a sort of pulley, *p*, formed by a short band of fibro-cartilage attached at its ends to the bone and provided with a perfect synovial sheath. Hence this muscle is also called the trochlearis muscle. From the pulley, its tendon, 4, is reflected outwards, downwards, and somewhat backwards, passing between the superior rectus and the eyeball, and then becomes attached to the outer side of this latter, a little behind its middle. The *inferior* oblique, the shortest of the ocular muscles, does not arise with the others from the bottom of the orbit, but from the inner and fore part of the floor of that cavity, and, passing outwards, and a little backwards, beneath the inferior rectus, wraps round the eyeball, and is inserted on the outer and hinder surface, beneath the external rectus. The chief action of the oblique muscles, which exactly antagonize each other, for the force of the superior oblique is exerted only from the pulley, appears to be to roll or rotate the eyeball on its antero-posterior axis, the superior oblique rolling its upper half inwards, and the inferior oblique rolling its lower half inwards. At the same time, owing to these muscles being inserted behind the transverse axis of the ball, they will also turn its anterior surface, *i. e.* the cornea, obliquely outwards and upwards when the inferior oblique acts alone, and outwards and downwards under the sole action of the superior oblique. When the two oblique muscles act together, they will turn the cornea directly outwards. It has furthermore been conjectured that these two muscles, being directed somewhat backwards, antagonize the recti, whilst these latter compress the eyeball so as to alter its shape.

The special movements of the eyeballs necessary for the purposes of sight will be hereafter described.

The Nerves and Vessels of the Eyeballs.

Besides the optic or proper visual nerve, from twelve to fifteen little nerves pierce the eyeball, to be distributed to its various coats, chiefly, however, to the choroid coat, and especially to the ciliary muscle and the iris, which is also partly muscular. These nerves, containing filaments from the third and fifth cranial nerves, and from the ophthalmic ganglion of the sympathetic (see pp. 115, 125), are therefore mixed nerves, motor, sensory, and nutritive. They are very slender, and very loose, or much longer than the distance they have to pass before they reach the eyeball, so that they are not liable to be stretched during its movements.

The circulation of blood through the eyeball is most abundant, and is most carefully provided for. Not fewer than a dozen small arteries enter specially its back part, besides numerous twigs in front, derived from the arteries of the ocular muscles. The number and fineness of these vessels, and of their companion veins, and also their length and tortuous course before they reach the eyeball, which renders it impossible to overstretch them, not only secure an ample supply of blood during the various movements of the eyes, and in all positions or efforts of the body generally, but also moderate the force of the heart, destroy any impulse, and equalize the distribution and flow of blood through the exceedingly delicate structures of the eyeball. The nutrient artery of the retina reaches that most delicate of all known tissues in a very remarkable way, for it pierces the optic nerve at a short distance from the eyeball, and, advancing snugly along its centre, enters the eyeball by a special little opening in the sclerotic, in the midst of those for the nervous cords, and so reaches the retina, in which its branches ramify.

The existence of this little artery is constant, not only in man, but in all mammalia; together with its accompanying vein, and their intermediate capillaries, it secures the vitality and safety of the retina, which, if its circulation were stagnant, would cease to be excitable by light, and, if this were obstructed, would speedily be destroyed by rupture of its blood-vessels and extravasation of blood. Of the other parts of the eyeball, the richest in blood-vessels are the choroid coat, its ciliary processes, and the iris; the sclerotic, like other fibrous structures, is not very vascular, and the cornea has only a few marginal capillaries, the greater part of it, as well as all the humours, being absolutely without blood-vessels. During the development of the eye, vessels do pass into some of these last-named parts; but in their perfected state, the nutrition of the humours must be effected by the vessels of the richly-supplied vascular choroid, ciliary processes, and iris, and the cornea must derive its nutritive fluid from the sclerotic vessels trespassing upon its margin.

The veins of the eyeball escape near where the arteries enter it, and are almost as numerous and as tortuous. Lymphatics doubtless exist, but their distribution is not well known. The arteries, veins, and nerves pierce the sclerotic by little oblique openings, so as not to weaken its walls, nor allow the choroid to bulge, nor the humours to run out.

The Coats of the Eyeball.

a. The sclerotic and the cornea, which together protect the contents of the eyeball and preserve its globular form, are quite continuous, though so different in appearance, the one as it were changing at a certain line into the other, but in such a way that the cornea often seems to be received into the sclerotic, as shown in the figure, like a watch-glass in its groove. The sclerotic, *s′*, occupies $\frac{5}{6}$ths of the antero-posterior circumference, and the cornea $\frac{1}{6}$th, so that the former constitutes $\frac{12}{13}$ths and the latter $\frac{1}{13}$th of the surface of the ball. The back part of the sclerotic apparently forms part of a true sphere; but in front, where it receives the cornea, it is slightly flattened. The cornea, *c′*, which is a segment of a sphere having a diameter in proportion to that of the sclerotic sphere of 7 to 11, is not quite circular, but a little wider from side to side than from above downwards, its average dimensions being about half an inch in the vertical, and a little more in the transverse measurement. Its convexity varies in different individuals, and in extreme cases produces modifications in the sight. It is most convex in early life, and flattest in old age.

The sclerotic behind is about $\frac{1}{24}$th of an inch thick, but it is gradually reduced to half that thickness towards its forepart; the cornea averages about $\frac{1}{25}$th of an inch thick. The thinnest part of the fibrous coat of the eyeballs, and therefore the most compressible part, is where the tendons of the straight muscles are inserted around it.

The white, semi-opaque sclerotic, tough and very difficult to tear, is composed essentially of white fibrous tissue arranged in interlaced bundles, mixed with elastic tissue; it is moderately vascular, and yields gelatine on being boiled. The cornea is also composed of fibres, but these are arranged more regularly, and form a dense tissue, easily separable into closely-connected layers or laminæ, as many as 60 laminæ having been so produced; it is non-vascular, and yields chondrin when boiled. At the junction of the two structures, the fibres of the sclerotic change their character and mode of arrangement, to build up a transparent instead of an opaque tunic. The ultimate fibres of both the sclerotic and cornea, under the microscope, are quite transparent; and when the cornea, in a dead eye, is subjected to pressure, it becomes opaque, and resumes its clearness when the pressure is removed. These facts seem to show that it is to the arrangement of the elementary component fibres that the transparency or opacity of these tissues is due. In front, the cornea becomes more condensed in structure, and is covered with a basement membrane and three or four layers of the epithelial cells of the conjunctiva; whilst its posterior part consists of a peculiar dense, structureless layer, so elastic that it curls up forwards when it is peeled off; it is not altered by boiling or the action of acids, like the fibrous part. It is lined internally, next to the aqueous humour, with a single layer of flat polygonal epithelial cells, like those of serous membranes. The substance of the cornea is very permeable to fluids, and in this way probably its nutrition is carried on. In disease, it becomes vascular, sometimes ulcerates, and heals with opaque specks or spots, or with a general opacity, which of course more or less interferes with the sight.

The sclerotic and cornea are both supplied with nerves, and become very sensitive when inflamed.

b. The *choroid coat*, *e*, or vascular and pigmentary tunic, is only $\frac{1}{200}$th of an inch in thickness. From the optic nerve, which perforates it behind, it reaches forwards coextensively with the sclerotic, to which it is everywhere held by a loose tissue called the *lamina fusca*, as well as by blood-vessels and nerves. Its anterior edge is firmly connected with a circular fibro-elastic band, which is found all round the inside of the eyeball, at the junction of the sclerotic with the cornea, and which is called the *ciliary ligament*, because it supports the radiated processes or folds of the anterior part of the choroid, called the ciliary processes. The circumference of the iris is also fixed to this ligament; and near this is a circular channel, named the *sinus circulosus*, seen cut across in fig. 21, which is considered by some to be a vein.

The *ciliary processes*, *b*, consisting of about 60 larger rays, measuring $\frac{1}{10}$th of an inch long and $\frac{1}{40}$th of an inch deep, with as many smaller ones interposed, are arranged in a circular manner around the interior of the eye, like the rays in the disk of a passion-flower. Their anterior ends, or tips, reach into the interval between the iris, *i*, and the crystalline lens, *l*, where they are bathed by the aqueous humour.

The choroid consists of a web of connective and elastic tissue, containing many black or brown pigment-cells, and supporting on the surface next to the sclerotic a number of curiously vorticose, or whorled veins, with which are numerous branching arteries, and next to the inner surface an immense number of exceedingly fine and closely-netted capillaries. Lastly, within these is a layer of black or brown pigment, consisting of hexagonal and neatly-fitted cells (see diagram No. 9, fig. 74), lying in a single layer at the back and sides of the eyeball, but more rounded in form and disposed in several layers in the fore part of the choroid and on its ciliary processes. In these processes, the capillary network is larger, and the whole structure firmer.

Connected all round with the ciliary ligament already described as situated at the junction of the sclerotic and cornea, and passing backwards from it in all directions to the ciliary processes and adjacent part of the sclerotic, is a thick yellowish-pink structure, composed of involuntary muscular fibres arranged partly longitudinally and partly in a circular direction, and called the *ciliary muscle*, *b*. It is a highly important structure, and must act in some way on the ciliary processes, and also through them and other structures on the crystalline lens, and perhaps on the cornea too.

The *iris*, *i*, is that remarkable coloured and perforated membranous curtain which is stretched across the interior of the eye opposite the junction of the sclerotic and cornea. Its circumference is attached by little bands, called the *pillars of the iris*, to the posterior elastic layer of the cornea; also to the ciliary ligament, and to the choroid coat. Its anterior surface is flat, and being provided with pigment-cells, and being visible through the transparent cornea, as shown in fig. 20, gives the colour to the eye in different persons: hence its name. A little to the inner side of its centre is the circular perforation, seen in the living eye as a black spot, on looking through the cornea, and called the *pupil*. This aperture, fig. 24, *p*, enlarges in a feeble light, and becomes smaller in a strong light, as may easily be shown by first covering the eyes of another person, and then exposing them to sunlight or to the light of a candle, or by first causing the eyes to be directed to a dark corner of the room and then to the window. It also contracts on looking at near objects, and dilates again on regarding distant ones. Its usual limits of size are from $\frac{1}{20}$th to $\frac{1}{3}$rd of an inch; but under the influence of belladonna it dilates so much, that the circular rim of the iris, which narrows as the pupil dilates, and the contraction of which is the active cause of the dilation of the pupil, almost disappears.

The iris consists of a web of connective and elastic tissue, which supports a rich supply of blood-vessels and nerves, a few involuntary muscular fibres, and a quantity of pigment-cells. Of these latter, some, of a yellow, brown, or dark hue, according to the colour of the eye, are situated in its substance or on its anterior surface; whilst others, invariably of a dark-brown or black hue, are crowded in layers at the back of the iris, where they form what is called the *uvea*. On the anterior surface of the iris, fig. 24, *i i*, its blood-vessels form two vascular rings, near the circumference and margin of the pupil, constituting the *circulus major* and *minor*. Between them are radiating vessels, which, covered by pigment-cells, form the lines seen on the front of the iris during life, and often presenting a very curious reticular appearance, fig. 24. The capillaries are not so numerous as those of the choroid coat. The muscular fibres are chiefly accumulated in the form of a ring placed at the back of the iris, near the pupillary margin, where they constitute the *sphincter pupillæ*, which widens the iris and contracts the pupil. Another set is also described as passing from the circumference towards the pupil, acting as *dilators* of that opening; and though some anatomists have regarded these latter merely as elastic bands, there is reason to believe that many are muscular, and pass from one surface of the iris to the other, so as to form slings in which the circular fibres are embraced.

The chief use of the iris is evidently to act as a stop or diaphragm, like those used in the construction of microscopes and telescopes, to shut out all the light but that which goes through the central portion of the crystalline lens; but, being, unlike those diaphragms, muscular and movable, it also regulates, under reflex influence, according to the varying intensity of external illumination, the actual quantity of light admitted into the interior of the eyeball. From injuries or disease, its margins sometimes cohere, and cause partial or total blindness of the eye by the exclusion of light. By a very delicate operation, that of making an *artificial pupil* or hole through the iris, sight is often restored. The anterior surface of the iris is brilliantly reflective, and gives the eye its special colour, which is peculiarly lustrous, independent of the sparkling which is due to reflection from the corneal and lenticular surfaces. The uvea, or intensely dark pigment on the hinder surface of the iris, together with that lining the inner surface of the choroid, converts all that part of the interior of the eyeball which is beyond the iris into a *dark chamber*, or *camera obscura*, in which vision takes place by means of the light admitted into it to strike upon the retina, and the walls of which immediately absorb all used-up light, which would otherwise be reflected from its sides, and cause confusion and difficult vision.

In children this pigment is usually darker than in adults. In them, and in delicate adults, the beautiful pale-blue tint of the white of the eye is owing to the thinness of the sclerotic coat in such cases allowing the dark pigment within to be partly visible through it; and blue eyes,—that is, eyes with a blue iris,—are owing to the deficiency of yellow or brown pigment in that membranous curtain, and the shining through it of the dark uvea. A few scattered, ramified pigment-cells are also found in all cases in the substance of the sclerotic coat. The pigment of the eye, corresponding with that of the hair, is darker in dark persons, and in the dark races of mankind, in the latter of which there are also numerous pigment-cells in the conjunctiva covering the sclerotic, which give the white of the eye a disagreeable patchy or streaky appearance. That the pigment protects the eye against the action of redundant light, is shown by its being darker in the inhabitants of hot countries, and of the polar regions; in the one case guarding it against the dazzling light of the sun, in the other from the glare of the snow. In Albino men and animals, in which the hair is light and the eyes are pink, the ramified, hexagonal, and roundish pigment-cells are all present, but they contain no dark pigment granules; and in such cases, excessive light is very dazzling and painful.

c. The *retina*, *r*, from *rete*, a network, the nervous or sensitive coat of the eyeball, on which the light makes its impression, is the most delicate of all the tunics of the eye, and beyond comparison the most beautiful structure in the whole body. It is placed next to the choroid, but does not reach so far forward, extending only from the entrance of the optic nerve, of which it appears as a sort of expansion, to near the posterior ends of the ciliary processes, where it ends in a wavy edge, or rim, called the *ora serrata.* From this edge, a very fine supporting membrane, not nervous, extends forwards on to the ciliary processes. The retina is also organically connected with the choroid on its outer side, and with the membrane which surrounds the vitreous humour, *v*, on its inner side; between these parts it is so suspended as to present a concave surface to the light which penetrates the eyeball, a most important feature in the optical construction of the eye.

During life this inner surface of the retina may be explored, by aid of a magnifying-glass, if a strong light be thrown directly through the pupil, when it appears of a reddish colour, owing to the blood in its vessels, and is seen to be traversed by the branches of the central artery of the retina and its accompanying vein. Examined directly after death, or removal from the living body, it is pinkish and transparent; but it soon becomes white, or semi-opaque, from imbibition of water.

In the very centre of the retina, that is, exactly in the antero-posterior axis of the eyeball, and *in the line of most perfect vision*, is seen an elliptical yellowish spot, about $\frac{1}{12}$th of an inch wide, called the *macula lutea*, first discovered by a German anatomist, Sömmerring, in the eye of a recently-drowned man. In the middle of this *yellow spot* is a dark circular depression, called by him the *foramen centrale*, but now known not to be a *hole*, but only a thinner portion of the retina, which is named the *fovea centralis*,—from *fovea*, a pit.

About $\frac{1}{10}$th of an inch to the inner side of and a little below the yellowish spot, and *not in the line of most perfect vision*, is the point of entrance of the optic nerve, named the *optic pore*, from which the fibres of that nerve spread out in all directions in the retina; here, too, the central artery and veins also enter and pass out. Around the optic pore, where the retina may be said to begin, it is about $\frac{1}{120}$th of an inch thick, but it gradually diminishes to $\frac{1}{240}$th of an inch.

The microscopic structure of the retina is most exquisite, surpassing even that of the denticulate layer in the cochlea of the ear. On its inner surface is a transparent glassy *limiting membrane*. Next to this are the expanded *fibres of the optic nerve*, wanting their double outline, and arranged in fine meshes. Outside this is a layer of grey *ganglionic vesicles* or *nerve-cells*, like those of the grey substance of the brain: these are more abundant in the hinder portion of the retina than near its anterior margin. Outside these is a *granular and fibrous layer*, consisting of two layers of granular nuclear bodies, and numberless remarkably fine fibres, which passing perpendicularly to the surface, may be traced inwards, it is said, to the branches of the ganglionic cells, to the terminations of the optic nerve-fibres, and even between these to the internal limiting membrane, whilst outwards they pass to be connected with the elements of the next and outermost layer of the retinal elements. This is the *columnar* or *bacillar layer*, the most beautifully regular and delicate combination of microscopic organic particles in the entire animal body. It consists of a single layer of evenly-disposed microscopic *rods*, called *bacillæ*, transparent, colourless, and highly refractive, packed closely side by side, like the seeds on the convex receptacle of a sunflower, and all directed from the outer towards the inner surface of the retina, and with the exception of those near the front of the retina, perpendicularly to the centre of the eyeball. Interspersed at the most regular intervals amongst these, are larger bodies of a similar appearance, and having a similar direction, called *cones*. These rods and cones are connected by the perpendicular fibres just mentioned with the vesicular and fibrous nervous layers of the retina; and although it would appear as if they were themselves nervous elements, or appendages to the nerves, this is not exactly determined, and their precise functions are yet quite unknown. The dimensions of these several parts will afford some idea of the complexity of the retinal structure. The nerve-vesicles are about $\frac{1}{1100}$th of an inch in diameter; the optic nerve-fibres, $\frac{1}{12000}$th; the cones, $\frac{1}{2500}$th; the bacillæ, or rods, $\frac{1}{14000}$th; and the perpendicular fibres are as fine as $\frac{1}{40000}$th of an inch in width.

At the margins of the yellow spot, the rods of the columnar layer, the fibres of the optic nerve, the granular nuclei, and perpendicular fibres, diminish in proportion, and then, towards the fovea centralis, fade away, so that, at this last-named dark central point, there is nothing left of the retinal elements but the cones of the columnal layer, a deep stratum of grey ganglionic nerve-cells, 7 or 8 cells thick, and the internal limiting membrane; yet this is in the line of the most perfect vision. The dark colour of the fovea centralis is owing to the choroid pigment appearing through, and the yellowish margin to some special but very delicate pigmentary substance, which is easily washed out by water.

processes. When lost, from accidental wounds, or in the extraction of cataract or the formation of artificial pupil, it is rapidly replaced.

The Physical Properties of Light.

The sensation of light in the eye is produced by a certain physical agent, or action, called *light*, which, without the existence of a sensitive organ, would pervade the universe unseen. The *sources* of light are the sun and the fixed stars, electricity, and combustion of all kinds, including phosphorescence. Its *nature* is not yet known,—whether it be corpuscular, or undulatory, or a form of force resulting from chemical action.

Light *radiates* in straight lines equally in all directions from its source; and it travels at the amazing velocity of 192,500 miles in a second.

Solar light is apparently *white*, but it has been shown to be *composed* of *red*, *yellow*, and *blue* lights mingled in definite proportions; and with these it also contains certain invisible rays which produce heat, and are called the *calorific rays*, and other invisible rays, which give rise to chemical action, called the *chemical* or *actinic* rays. Artificial lights are less intense than that of the sun, and vary in colour, heating power, and chemical influence. Some are nearly monochromatic, that is to say, of one colour only, as the flame of alcohol burned on salt, which gives a nearly pure yellow light.

Non-luminous *opaque* bodies, such as the planets and their satellites, including, of course, our own earth and the moon, and most terrestrial objects, reflect and absorb light in different degrees and manners. By reflecting or throwing back more or less light, they become visible to us; if they reflect all, or nearly all, they appear white or whitish; if they absorb nearly all, or all, they appear dark or black: an intermediate action produces a grey or neutral tint. By intercepting light, opaque bodies cast *shadows*.

Opaque bodies are not, however, simply black, grey, or white, but present great variety of *colour*. This is owing to their absorbing some of the three *primary* coloured lights—red, yellow, and blue, of which white light is composed, and reflecting the rest. A perfectly red body, for instance, absorbs the blue and yellow rays, and reflects the red ones; whilst blue and yellow bodies reflect those coloured rays respectively, and absorb, the former the red and yellow ones, and the latter the red and blue. If a body instead of absorbing two of the three primary colours and reflecting one, absorbs one and reflects two, different effects are produced: thus, the absorption of the red rays only and the reflection of the blue and yellow, gives a green colour; the reflection of red and yellow gives orange; and that of red and blue, purple. Green, orange, and purple, being compounds of two primary colours, are called *secondary* colours. Bodies which reflect more or less of all three of the primary colours vary in hue accordingly; and the colours produced,—such as russets, drabs, and olives, according as the red, yellow, or blue predominates, and greys, in which all are mingled,—are called *tertiary* colours. When all the white light falling on and reflected by a surface is decomposed by partial absorption, the reflected colour is intense; but when some of the white light escapes decomposition, the colour of the object is more diluted. Any colour or tint, whether primary or secondary, which, in regard to another, is necessary to form white light, is called its *complementary* colour: thus, red is the complementary of green, and green of red; orange and blue are each complementary to the other; and so are yellow and purple.

As in the case of sound, so of light, the angle at which it is thrown off from any surface, or the angle of *reflection*, equals the angle of *incidence;* and the paths of the incident and reflected rays lie in the same plane. If an opaque body have a polished surface, like that of a mirror, the reflected light gives rise to images of objects before it. This is called *regular reflection.* If the surfaces be multiplied, the reflected images are broken, and if actually rough, the reflection is *irregular*, and the light diffused without the formation of images at all.

Translucent bodies reflect some light, and transmit some; being intermediate, in these respects, between opaque and transparent bodies. They may also decompose white light, and so reflect and transmit various hues.

Transparent bodies, whether gaseous, liquid, or solid, such as air, water, and glass, *transmit* light almost completely, if it falls on them more or less directly. If, in addition to this, they decompose light by partial absorption, they are coloured as well as transparent. As, probably, there is no substance wholly impermeable to light, so there is none which is absolutely permeable to it; for even the atmosphere, though ever so clear and bright, absorbs some of the rays as they pass through it, and thus gives rise to the phenomena of *aerial perspective.* Transparent bodies, if their surfaces are smooth or polished, as water or glass, reflect light which falls on them within certain angles, and so give rise to images, more or less perfect, of adjacent objects.

But the most important property of transparent bodies, or of transparent *media*, as they are called in optics, is that of their *bending* or *refracting* the swift-moving rays of light which fall at particular angles upon their smooth or polished surfaces. This phenomenon is called the *refraction of light.* When the rays of light continue to travel through any medium of uniform density, or when they pass from one medium to another of a different density, in a direction *perpendicular* to the surfaces by which the media are in contact, they move on in perfectly straight lines. But whenever they leave one medium and enter another in an *oblique* direction to the surfaces of contact, they are bent out of their straight course, or, as it is called, are refracted. On passing from a rarer to a denser medium, as from air into glass, the rays are bent *towards* a line perpendicular to the surface at the point of incidence; and they are bent *from* such a perpendicular on passing from a denser to a rarer medium. The incident and the refracted rays always lie in the same plane; and the amount of refraction increases after a certain law with the obliquity of the incident rays. Different media have different refractive powers, the relative values or the *refractive indices* of some of which are as follows, vacuum being taken as 1·:—air, 1·0003; water, 1·33; flint-glass, 1·642; and the diamond, the highest known, 2·755. The refractive power bears a general relation to the density of a medium, but is not absolutely in conformity with it,—combustible substances having a greater refractive power than their density would indicate.

The different coloured rays which compose white solar light are refracted by any given medium in different degrees, or, as it is said, they have different *degrees of refrangibility.* Hence, when a *circular beam of solar light* is refracted twice through a prism, its different coloured rays are differently refracted or bent out of their course, and thus are *dispersed*, so that when received on a screen, an *elongated coloured spot* called the *prismatic spectrum* is formed, as the result of this mode of decomposition of white light.

It is to the refraction of light that the remarkable properties of the ground and polished pieces of glass, or rock crystal, or any other transparent body, called *optical lenses* are due. These lenses are of various forms, but are represented by two types, viz., *convex* and *concave* lenses.

Of convex lenses, the one in most common use is the *double-convex* lens, which is a circular piece of glass, having its two surfaces ground and polished spherically convex, so that it is thickest in the middle. If a watchmaker's lens, which is a glass of this kind mounted in a horn frame, be held with one face *directly* towards the sun, a small round bright spot or *image* of the sun will be formed on a piece of paper, or on the back of the hand, placed at a short distance from the other face. The place at which this spot is smallest, most defined, brightest, and hottest, is called the *focus* or *focal distance* of the lens; and when, as in this case, or in the case of a candle or any illuminated object situated very remotely, the rays from the several points of the object enter the lens in *parallel* lines, the place at which the best and clearest image is formed is called the *principal focus* or *proper focal distance* of the lens. Each lens has two principal foci, one opposite the centre of each surface, for the lens will act either way.

Fig. 22 represents the section of a double-convex lens, the axis of which corresponds with the line *b b'*. An arrow, *a b c*, is placed directly opposite to one surface of the lens, and an *image* of the same, which is inverted, is shown on the other side at *a' b' c'*. The lines passing from one to the other through the lens show the direction of certain of the rays of light proceeding from the arrow, *a b c*, to form, by the effects of refraction, the inverted image, *a' b' c'*. In this case, the object is so near the lens, that the rays of light from the several points of the former *diverge* as they proceed to fall upon the latter.

Of such diverging rays from every point of the arrow's surface, those from the central point, *b*, form a luminous cone, or conical pencil of rays, called a *direct pencil;* whilst those from all the other points up to the extremities, *a*, *c*, form more or less *oblique pencils*. The central ray of the direct pencil *b* passes through the lens unchanged in direction, whilst the divergent rays of that pencil are twice refracted, first towards a perpendicular to their point of entrance into the lens, and then from a perpendicular to their point of emergence from it, and so are made to converge on the other side of the lens, and meet the central ray at or near the common focus, *b'*, where, accordingly, an image of the point *b* is produced. The oblique pencils, of which only the two extreme ones, *a* and *c*, are represented, undergo similar, though not such regular refraction, and, *crossing* each other in the centre of the lens, converge on the opposite sides of the direct pencil, *b b'*, and so form images, at the focal points, *a'* and *c';* and as all the pencils, from the intermediate points between *a*, *b*, and *c*, are similarly reflected and made to converge to their respective intermediate foci, a complete but *inverted* image is formed by the grouping together of the assembled foci,—an image which may be received on a piece of white paper, or any other proper and convenient screen. It is scarcely necessary to add that on exactly the same principles inverted images are formed of groups of objects, or of whole scenes or landscapes.

To produce perfect images with these optical lenses, several points have to be attended to in their construction and their use:—

a. First, as the different coloured lights composing white light undergo different degrees of refraction, the images formed by an ordinary lens are, in consequence of the partial dispersion or decomposition of the light, surrounded by a fringe of prismatic colours. Such a defect is said to be due to *chromatic aberration*, or the error of *dispersion*.

b. Lenses with spherical surfaces—the form usually given to them for facility of manufacture—have another defect, that of *spherical aberration*, which is due to the fact, that owing to the rapidly-increasing obliquity with which the rays fall on the curved surface, as this recedes from the centre of the lens, the degree of refraction becomes relatively greater, so that the rays passing through nearer and nearer to the margin are brought to a focus sooner and sooner, in proportion to the central rays. Hence arises an *indistinctness* of every part of the image, especially of near objects, which give off divergent rays.

These two defects, dependent on the construction of lenses, may in practice be diminished by the employment of *perforated stops* or *diaphragms*, which cut off the marginal rays; but in the best optical instruments they are further and almost completely prevented, or corrected, as it is called, by building up lenses of two kinds of glass, having different dispersive powers, and ground with different curves so that the one will counteract the dispersive and undue marginal refractive effects of the other.

In the use of lenses, several other causes of defective images exist.

c. In the first place, the position in which the clearest image of any object is formed behind the lens depends on the distance of that object in front of the lens. For remote objects, from which the rays are parallel, the best image is formed in the principal focus; but for nearer objects the focus continually recedes from the lens, until at last, when the object has reached the principal focus in front, the rays from it, after being refracted, themselves become parallel, and form no distinct image at all. To obtain good images of objects at variable distances, then, it is necessary to adjust the distance between the lens and the surface or screen on which the image is to be received, so that it can be shortened for distant objects, and lengthened for near ones. This is accomplished in optical instruments by making the lenses movable. In the camera obscura, which consists of a dark box or chamber, having a lens fitted into one side of it, and a proper screen of paper or ground glass on the opposite side to receive the images formed of objects in front of the lens,—provision is made for the proper adjustment of the focal distance, by fitting the lens into a sliding tube: but the screen might be made movable; or both the lens and the screen. Altering the power of the lens would also have the effect of remedying this error, but practically this can only be done by substituting one lens for another. This defect is named *distantial aberration* or the *error* of *distance*.

It must be borne in mind, also, that the size of the image also varies according to the distance of the object, being smaller according as this latter is further off; and, moreover, that the more convex the lens, the shorter the focus, and the smaller the image it produces.

d. The image even of a straight line formed by a double-convex lens is always *curved*, or *concave* towards the lens; and hence, if it be received on a straight or plane surface, it is either defective at the margins or in the centre. This is called the error from *curvature*. It is met by making the recipient surface or screen also curved or concave, as is always done in the best kind of camera obscura.

e. There is another error, called *distortion*, which principally affects the images of those parts of very long straight objects which lie towards the margins of the field; for it depends on the gradually-increasing distances of those parts from the lens,—the images of those parts being accordingly smaller in proportion to those of parts lying opposite the centre of the lens.

In practice, the effects of curvature and distortion are lessened by cutting off the marginal portion of the field by a perforated diaphragm, so as to limit the operation of the lens to its central part.

f. Lastly, there is an error called *confusion*, which depends on the increasing irregularity of the refraction for the rays which fall more and more obliquely on to a lens. Its effects are lessened by shutting out the marginal or most oblique rays, but can only be entirely prevented in optical instruments by altering the position of the lens, so that the rays from any object, or part of an object, may fall on it directly instead of obliquely.

The Optical Action of the Eye.

The essential optical condition of perfect vision is the formation on the retina of distinct images of external objects; and such images may be seen on the retina at the back of dead eyes properly prepared and supported in position, and even in the living eye by aid of an instrument called an *ophthalmoscope.*

The optical apparatus of the eye is not a single lens, but a combination of several refractive media, having curved surfaces,—viz., the cornea, the aqueous humour and the crystalline lens in front of the vitreous humour,—which together form a sort of compound double-convex lens. Of this the greatest convergent power is exercised by the cornea and aqueous humour, the refractive powers of which are nearly equal, and much greater than that of the air. The crystalline lens, being placed between humours of nearly the same density, has a slight additional convergent effect, but not nearly so much as is often attributed to it in vision, or as it really has when removed from the eye, and acting in air.

The mode in which the rays of light are refracted in the eye is shown in Fig. 21 on the right side, which may be compared with Fig. 22, and studied by aid of its description. The actual focus of the entire optical apparatus of the eye, when adjusted for different distances, is so arranged as to fall on the retina, where, as on a screen, *small, distinct,* but *curved* and *inverted* images of external objects, as of the arrow in the figure, are delicately but clearly painted.

In comparison with the very best compound artificial lenses, the perfection of the optical part of the eye is truly wonderful, whether we consider its construction or its mode of use.

a, *b*. The eye is practically free from *spherical aberration*, and, according to good authority, from *chromatic aberration* also. Both of these possible defects are diminished by the marginal rays being cut off by that elegant, movable, and duly-regulated perforated stop or diaphragm, the iris; but they are probably absolutely corrected,—the former by the gradually diminishing density and refractive power of the crystalline lens towards its borders, so that the tendency to over-refraction near these is counteracted, —and the latter, most probably, by different and mutually corrective dispersive powers being allotted to the substance of the laminated cornea, the fluid of the aqueous humour, and the capsule and complicated structure of the lens. The use of the last-named part in the human eye and in the eyes of animals seeing through air is, indeed, probably chiefly corrective.

f, e, d. The errors known under the names of *confusion*, from oblique rays, and *distortion* from the varying distances of the parts of the same objects, are not only diminished in the eye by the cutting off of the marginal rays by the iris; but more than this, they are not in any way perceptible to us in the use of this marvellously perfect organ,—not merely as regards vision through the central part of the eye, but in lateral vision also. The error from *curvature* is also remarkably provided against by the concave form of the surface of the retina,—a form dependent on the spherical shape of the eyeball behind, which is universal in all eyes constructed on the same optical principles as the human eye, and which has certainly its optical as well as its obvious mechanical advantages of convenience and strength.

c. The avoidance of *distantial aberration*, by an intrinsic, rapid, and perfectly-regulated power of *focal adjustment* to objects at different distances is one of the most astonishing endowments of the eye, the sphere of whose perfect and useful action it enlarges to so great an extent. It also constitutes one of the most striking illustrations of organic contrivance to be found in the whole body. To see distinctly at the same time, two objects placed in the same line one before the other at a certain distance apart is impossible; but we can most easily and swiftly look first at one and then at the other, and thus distinctly perceive both. In this act, which, for the purposes of experiment, should be performed with one eye only, or the sensations produced by directing the two eyes to a common object will confuse the observation, a certain change of which we are quite conscious takes place *within the eye*, which serves in some way to adjust the focal distance between the optical centre of the eye and the retina. The active change appears to take place by means of some internal muscular contraction, which occurs in looking at near objects, whilst in looking at distant ones the parts concerned resume their ordinary and unconstrained position. This entirely corresponds with the sense of effort and fatigue which accompanies near vision, if prolonged for any time, and with that of relief and rest in subsequently looking at remote objects.

The nature of the changes which produce the necessary adjustment has long been disputed.

A certain contraction of the pupil, which invariably takes place in near vision, may assist, by shutting off the marginal rays, in making the image more distinct; but it is not the only change that takes place, and not the efficient change; for we can adjust the eye in strong lights, when the pupil is much contracted, and in feeble lights when it is much dilated; and the same can be effected when we look through a pin-hole in a card, far finer than the aperture in the pupil. The contraction of the pupil seems rather to be a consentaneous movement, having reference to the quantity of light, which is relatively greater and more intense from near objects.

Either, then, the distance between the retina and the optic centre of the eye must be lengthened in near vision by some movement of the lens or by a general elongation of the antero-posterior diameter of the eyeball, or else the refractive power of the eye must be increased, for near vision, by some increase in the convexity of the cornea, or some change in the shaps of the lens itself. Evidence is wanting to show that the eyeball is observably lengthened in its antero-posterior axis, nor has a simple movement forward of the lens been certainly demonstrated. Theoretically speaking, a very slight increase in the convexity of the cornea, so slight as to be exceedingly difficult of detection, would suffice to account for the whole adjusting power of the eye for near objects, inasmuch as the refractive power of the cornea and aqueous humour together is so much greater than that of air; but this change, so far from having been demonstrated, has been looked for by good observers in vain. Recent observations have been made which are considered to prove that, during near vision, the lens itself is really altered in shape, in such a way, that its anterior surface becomes much more convex, and so advances forward, whilst its posterior surface is likewise somewhat increased in convexity. The mechanism of this change is not quite clearly explained; but if it really so happens, the focal adjustment of the eye depends on conditions altogether inimitable in the case of artificial lenses. The facts which are believed to prove the occurrence of a change in the form of the lens, are certain changes observed in passing to near vision, in the size and position of the two images of a luminous object, reflected from the surfaces of the lens, whilst the image reflected from the cornea remains unchanged. Unless these appearances are due to some other conditions, as for example to the effect of an increased convexity of the cornea, with or without a forward movement of the whole lens, or to some change in the position of the entire eyeball, it must be admitted that they are owing to a change in the shape of the lens.

Whatever its nature may be, the adjustment itself is undoubtedly accomplished by the agency of the ciliary muscle and the muscular fibres of the iris, which are both attached to the line of junction of the cornea with the sclerotic; and it is difficult, looking to the exact connections of these parts, to conceive how the muscular fibres in question should operate in any way on the lens so as to change its form without at the same time somewhat shifting its position, and perhaps also affecting the projection of the cornea, by pulling inward its margin, together with the anterior part of the sclerotic all round.

The movements of the iris under variations of light are simple reflex acts, though in near vision the contraction of the pupil appears to be consentaneous. Instances, though very rare, are known of the contraction and dilatation of the pupil being in some way, perhaps indirectly, under the influence of the will. The contraction of the pupil, by the circular fibres, is regulated through the third cranial or motor-oculi nerve; and its dilatation, through nervous influence from the spinal cord, conveyed through the branches of the sympathetic nerve. The action of the ciliary muscle is also usually involuntary and consentaneous with that of the iris; but it may be, for what we know, sometimes independent; and, quite as an unusual state of things, it has occasionally shown a subjection to the control of the will. What nerves are concerned in its government is not known, but it is presumed they are branches of the third nerve.

The usual limits of focal adjustment, and therefore of distinct vision, in ordinary eyes, are from about eight inches to indefinite distances, according to the varying intensity of the light. But there are persons, called *short-sighted*, who see things well much closer to the eye than eight inches, but cannot see them distinctly at even a moderate distance; and there are other persons, called *long-sighted*, who can see distant objects remarkably well, but not very near ones. These peculiarities of sight do not depend, however, on any deficiency of adjusting action, which is quite perfect in such eyes for their own distances, but on a certain fundamental excess or defect in the refractive power of their transparent media. In *short sight*, the cornea is prominent, and the antero posterior diameter of the eye is said to be unusually long: hence the eye over-refracts the rays of light, and the proper focal distance falls short of the retina. The remedy habitually resorted to consists in bringing objects very close to the eye; but the best corrective is to wear *concave* spectacles, which, by causing divergence of the rays, counteract the over-convergent effect. In *long sight*, the cornea is relatively flat, and probably also the antero-posterior axis of the eye is shortened; the rays of light are insufficiently refracted, and the focal distance falls beyond the retina. The remedy is to hold things away from the eye, or to wear *convex* glasses to help the too feeble convergent power.

The Physiological Action of the Retina.

Irritation, electrical shocks, blows, or pressure, applied through the globe of the eye to the retinal expansion of the optic nerve, produce a sensation of light; but the proper stimulus of the retina is light itself, which appears to act by producing some change of condition in that membrane, the effects of which are propagated along the optic nerve-fibres to the sensorium, where the actual sensation is felt.

There is one part of the retina—namely, the *optic pore*, or entrance of the optic nerve, on which, as has been shown by experiment, light is incapable of exciting any distinct sensation; and this part is, as it were, purposely removed *out of* the direct line of vision. There is another part of the retina on which visual impressions are the most distinct, namely, the central depression of the *yellow spot*, which part is *in* the direct line of vision. The rest of the retina is perfectly sensitive, but is used only in general, not in particular vision. As at the optic pore, which is insensible, the retina consists only of the optic nerve-fibres just spreading out, it would seem that these fibres themselves are not directly sensitive to light, but take note of changes induced by that agent, in one or more of the other elements of the retina, of which the cones and the grey vesicles most abound in the seat of distinct vision, viz., the centre of the yellow spot.

The visual perceptions finally realized in the sensorium are not referred, as in the case of touch, taste, and smell, to the place where the stimulus acts on the nervous extremities, that is, to the interior of the eye where the image is received; but as in the case of hearing, though far more definitely both as to character and direction, they are referred to their external causes, the luminous or illuminated objects from which the rays of light immediately proceed. This *outward projection* or *outness* of our visual sensations is an ultimate fact, of which no explanation has been given. It is evidently essential to the usefulness of sight considered as a means of acquiring knowledge of the presence, form, colour, position, and motion of the many objects around us.

Intimately associated with this outward projection of vision is the fact that we see things *erect* through the agency of an *inverted* retinal picture; for outward vision is necessarily in a particular direction, that is to say, we see things not only out of the eye, but along certain lines which are nearly, if not quite, perpendicular to the retinal surface engaged. Now as this surface is concave, the upper half of the retinal picture produces an outward perception of things below the horizontal line, and the right half of that picture, of things to our left side; and so on:—that is to say, in the very direction in which these objects are placed, which correspond with the inverted picture. This has been expressed under the general statement that there is a law of "*visible direction;*" but *optically* speaking, there is no such law; for of the many rays emanating from given luminous points, only the very few which fall directly on the centre of the cornea reach the retina perpendicularly to its surface. But there must be a *physiological* condition of a visible direction, owing to which we see things in their true position,—that is, along imaginary lines proceeding to them from the parts of the retina on which their images fall; and such lines must have a direction more or less perpendicular to those parts of the retinal surface. Indeed, the outness of vision implies some such physiological result. The luminous spot or ring produced by pressure on the eyeball is seen exactly on the opposite side to the seat of pressure, that is, in a direction perpendicular to the point of the retina which is thus excited. So, too, certain ocular spectra, of which we shall presently speak, and which depend, not on rays of light reaching the retina, but on particular states of that nervous membrane, are seen in a similar outward and perpendicular direction, and therefore apparently erect. It is open to conjecture that the rods and cones of the columnar layer of the retina, which are planted perpendicularly on its outer surface, may have some relation to the physiological phenomenon of visible direction.

Some have conceived that the condition of erect vision from an inverted image implies some primitive inconsistency—say in the infant state—between the senses of sight and touch, which has to be corrected by experience. But there is no such inconsistency: for the hand put forth to touch any object has its image traced on the corresponding part of the retina with the object itself, and the feet are pictured in conjunction with the ground; the reversal on the retina is not partial, but complete; it affects the visible parts of our own bodies as well as extraneous objects; hence there is nothing to unlearn or to correct by the aid of the touch. The two senses act differently,—the one feels at the surface touched, the other sees outwardly and in a pre-arranged definite direction; but the notions derived from both are, from the very first, harmonious and consistent.

In order that the retina should be roused to vision, a certain-sized portion of it must be excited by the light. It has been computed, however, that an image which occupies a surface so minute as $\frac{1}{34500}$th of an inch is sufficiently large to be seen. Lines can be more readily seen than spots; and bright objects, such as particles of gold, can be seen of smaller size than less brilliant ones. A certain amount or intensity of light is necessary to vision; and, in what appears to us to be absolute darkness, there is still some light. A certain time is required for light to make an impression on the eye; hence, swiftly-moving bodies, as balls fired from a cannon, are invisible when they cross our path. Lastly, when an impression is made on the retina, it has a certain duration, as is proved by the non-interference of the act of winking with continuous vision, and by the appearance of a circle of light seen on whirling round a stick ignited at one end. The duration of a bright light is usually about one-eighth of a second,—but it varies in different persons. The influence of any given quantity of light, its rapidity of action, and the duration of its impressions on the retina, are modified by the previous state of that membrane,—all being increased when it has been previously dark, and diminished when it has been just before exposed to a stronger light. A great excess of light is painful to the eye, and will even permanently destroy the power of the retina. A defect of light, if long continued, will also cause blindness, from want of exercise of the nervous tissue. Changing from dark to light is always trying to the eye until, by the contraction of the pupil, the rays are partly excluded, and the retina becomes accustomed to the excessive stimulus. A change in the opposite direction from light to dark is gradually compensated for on opposite principles.

The general exhaustion, which the retina, like other nervous structures, undergoes from use, is restored, partly, perhaps, during the frequent act of winking, but more effectually by the deliberate closure of the eyelids, by the change of the eye from one object to another, and by the providential arrangement of an alternating night and day. The effects of partial and local exhaustion of the retina are very curious, giving rise to what are called *ocular spectra.* Thus, if the retina be relatively exhausted at one point by looking steadily at a white spot on a black ground, and the eye be then turned on to a sheet of white paper, a dark spot or *dark ocular spectrum* of the same size as the original white one will for a short time be perceived,—the reason being that the part of the retina exhausted by looking at the white spot is less susceptible of the action of *a given* quantity of light than the unexhausted surrounding portion, which corresponded with the black ground. If, in the first part of the experiment, the spot be black, and the ground white, then the resulting spectrum will be *lighter* than the rest of the white paper.

There are other spectral phenomena dependent on various kinds of irritation of the retina, such as blows, the motion of the blood in the retinal blood-vessels, congestion, or inflammation; and there are others again which are caused by altered conditions of the optic sensorial nervous centres of the brain. Besides this, there are appearances in the field of vision called *muscæ* (flies), due to our perceiving things actually in or on the eye,—as fixed patches on the retina itself or in the crystalline lens, causing *fixed* muscæ, or movable particles in the vitreous humour or on the surface of the cornea, causing *muscæ volitantes,* or *flying* muscæ, which look like spots, streaks, strings of beads, or hairs.

The most remarkable spectra are those dependent on the relative exhaustion of the retina in regard to the different-coloured rays of light. Thus, if a red wafer be looked at steadily, and the eye be then turned on to a sheet of white paper, a round greenish spot will soon be perceived: if a green wafer be thus looked at, then the coloured spot on the white paper will be pink. In a word, the colour of the spectrum is, in all cases, complementary to that of the object first looked at, so that a blue wafer gives an orange spectrum, and so on;—the cause being that the retina is so exhausted of excitability to the colour first looked at, as no longer so readily to perceive the corresponding coloured rays of the white light coming from the surface of the paper, but only the remaining or complementary rays. Coloured spectra, due to a similar partial exhaustion of the excitability of the retina, are seen even when the eyes are closed after having looked at the sun, or at any coloured light. In all cases, by prolonged watching, the colour of the spectrum is seen to change, owing to a succession of exhaustive changes in the retinal excitability for particular coloured lights.

It is owing to the same principle, that complementary colours, placed side by side, are not merely harmonious, but mutually heighten each other's effect on the eye, which shifts its regards from one to the other. But non-complementary colours injure or deaden one another. This is well known to artists and decorators.

Of the primary, secondary, and tertiary colours, the first are the most exciting to the eye, and they are the most sparingly used in natural objects; whilst the more quiet secondary, and especially the tertiary hues, prevail. Of the primary colours, blue is the least exciting, and red the most irritating. Art, whether historical, landscape, or decorative, and custom as to dress, also exhibit an attention to these facts; for pure and gaudy colours are either employed scantily, or for the purposes of attraction only, whilst the mass of colour used is either diluted or subdued.

In some persons—in many more, indeed, than would be supposed—the sensibility of the retina, though perfect as to light generally, so that the visible forms and general characters of objects are plainly enough perceived, is defective as to certain impressions of colour. In some cases the defect exists in regard only to the lighter tertiary tints; in other cases the secondary colours are not all distinctly recognized; and in a third set, fewer in number, but exhibiting the most striking infirmity, the insensibility relates to one of the primary colours,—for in them even bright red is indistinguishable from green. Such persons see no difference in colour between cherries or holly-berries and the leaves of the tree or shrub on which they respectively grow. The most ludicrous mistakes are related of them. To them both reds and greens appear to be brown; and it is supposed that the explanation of such cases, and of the less marked ones also, is, that red light makes little, and in extreme cases, no impression of colour at all, but is simply black or dark. Persons thus afflicted are called *colour-blind.* When seriously affected, it is obvious that they are unsuited for many occupations; and the failure to distinguish green from red must disqualify any one from properly discharging such duties in railways or steam-boats as require the recognition of those-coloured signal lights. The cause of this partial colour-blindness is not known: it does not seem to reside in the refractive media of the eye, but either in the retina or in the optic sensorium.

Vision as a Source of Knowledge.

The little, distinct, but inverted pictures formed within the two eyes, being translated by the mind into outward and erect projections corresponding to the objects in the field of vision, we directly obtain thereby a knowledge of certain *appearances* or *apparent qualities* of those objects; namely, of their *apparent size,* their *apparent* or superficial *shape* and *colour,* their *apparent direction* or *position in the visual field,* and their *apparent motion in it.* But it is only indirectly, and by means of further experience and inference, that we arrive at conclusions, founded on our observations of those appearances, concerning the *real size, form, colour, position,* and *motion* of the objects external to us. The apparent qualities of objects, and their real size and colour, can be determined from observations with one eye only; but in estimating by sight alone, the real form, real position, and real motion of objects, we derive important assistance from the combined use of the two eyes.

a. Apparent and Real Magnitude of Objects.—The field of vision of each eye measures vertically about 120° of a circle, and horizontally about 180°, that is to say, lines drawn from the centre of the eye to the upper and lower, and to the lateral boundaries of that area, form angles of those dimensions in the eye; and if those lines be prolonged backwards to the retina, they will make corresponding angles in that direction. These angles are the *visual angles* of the whole field of vision. Now, the *apparent magnitude* of any object lying in the visual field, whatever its actual size, and at whatever distance it may be, corresponds with or is determined by the angles formed in the eye by lines drawn from the extreme points of its circumference through the centre of the eye to the retina. Taken in any given direction, such an angle is the visual angle of the object; or the object is said to subtend that angle:—for example, the moon subtends an angle of half a degree, or that is the visual angle of the moon.

But the same object, say the human figure, necessarily subtends a larger or a smaller angle according as it is nearer or more remote from the eye; and again a small object near at hand may subtend an equal angle with a larger one at a greater distance, in illustration of which fact, a pin one inch long held seven inches from the eye will cover a man forty feet off, and a threepenny-piece six feet off will about hide the moon. Hence it is obvious that sight teaches us directly apparent magnitudes only, and that our knowledge of real sizes,—which is ultimately referred to some arbitrary standard, as a barleycorn, a foot, a yard, or metre,—is obtained by experience, by comparison with objects of known dimensions, and by making due allowance for their respective distances.

b. Apparent Shape and Real Form of Objects.—The only forms seen by one eye are plane figures of *two* dimensions, length and breadth, bounded by straight or curved lines. But for the apprehension of solid or cubical forms of *three* dimensions, viz., length, breadth, and thickness, by means of sight, the two eyes are used in a peculiar manner together.

For this purpose both eyes are turned directly towards any given object, in such a way that lines prolonged from their axes would meet at that object, and its image would be received exactly on the centres of the two retinæ, which parts have a natural correspondence in action. When this is so, the images of all surrounding objects fall upon surrounding parts of the two retinal surfaces, which are also said to correspond, though, of course, from the complete inversion of the picture, they are on opposite sides of the central part. Under these circumstances, the two pictures are not seen separately as if referrible to two objects, but are combined by the mind, so as to be referred to a single object. It is this which constitutes *single vision with two eyes.* When, on the contrary, the two eyes are not made to converge to a given object, and when, therefore, lines prolonged from the axes of the eyes do not meet in that object, and the images of that object formed in the two eyes do not fall on corresponding points of their retinæ—as takes place in squinting, or in the displacement of one eyeball in its socket by lateral pressure, or as happens, in regard to an object at one distance, when we fix the eyes upon another object in the same line, but at a different distance,—then the impressions made on the two retinæ are not combined, but are separately distinguished by the mind, and *double vision* is the result. Why certain parts of the two retinæ so correspond that images of the same object received upon those parts are combined into a single impression, whilst if they be received upon other parts they are not, is not known to us. It does not appear to be the result of habit, but rather of some fixed structural condition; and it is regarded by some as due to a peculiar arrangement of the fibres of the optic nerve, which decussate in the optic commissure, and which are supposed to bring certain parts of the two retinæ into ultimate harmony in the sensorium. But even then the actual combination of the two impressions, like those of hearing, smell, and taste, still remains to be accounted for, as the result of some mental operation, intuitive, experimental, or rational.

The centres of the two eyes being about two and a half inches apart, it is necessary in order that these organs should be directed to any given object within a moderate distance for the purposes of single vision, that the optic axes should be made to converge to that object. For remote objects,—it is said beyond 120 feet,—this convergence ceases to be necessary; and the optic axes remain parallel for all further distances. This difference in the lines of vision of the two eyes for near objects is called the *binocular parallax*, the measure of which for any given distance is the angle formed by those two lines at the object itself. At a distance of 12 feet this angle is about 1°.

The convergence of the eyeballs is accomplished by the internal recti muscles of both eyes, which, though under the influence of the will in the side-to-side movements of the eyeballs and in voluntary squinting, act in this instance consentaneously. The return of the eyes to a state of parallelism is, probably, a passive phenomenon, dependent on the cessation of the contraction of the internal recti muscles, on the then equally-balanced tonic state of both external and internal recti, and on the general elastic resilience of all the parts connected with and surrounding the eyeballs. Permanent convergence of one or both eyes constitutes squint, the resulting double vision from which is soon avoided by a neglect of the weaker of the two impressions. Divergent squint is rare, and a voluntary power of divergence has probably never been distinctly observed.

But not only do the two eyes, when properly converged towards any near object, occasion a combined or single impression in the mind, but this single impression also possesses certain characters by which the mind at once recognizes the solidity, roundness, or relief of that object: that is to say, the mind acquires, by a combination of the two plane figures presented to the two eyes, a notion of the *real form in space*, or *cubical form* of the object so looked at. The two plane figures formed in the two eyes, of a near solid object within the range of the binocular parallax, are necessarily different, or represent two different aspects of the same solid body,—one, as it were, showing more of its left side, and the other more of its right; and it is by a combination in the mind of these two different perspective impressions of the same object, that the idea of its roundness or solidity is produced. The figures or images formed in the two eyes of any near solid object do not, therefore, exactly correspond, though they fall on corresponding points of the two retinal surfaces. The effect of the two eyes in giving the notion of solidity is well illustrated in that most ingenious philosophical instrument called the *stereoscope*, now so generally in use, which produces its magical effects of solidity and relief, by the combination, through optical means, of two pictures of the same subject taken at different points of view, and showing, therefore, two different aspects of it. In the case of a distant object, beyond the range of the binocular parallax, the two eyes perceive practically the same aspect of it, and apparently there is no more notion of relief than can be obtained with the use of one eye only. Hence the distant parts of landscapes and clouds are not seen in real relief; and this is true also of the distances in all stereoscopic views, which therefore still look natural. In regard to all such distant objects, and to objects viewed with one eye only, our notions of their solidity and roundness are due either to our previous knowledge of the fact, to some comparison with known objects, to some inference from the effects of light and shade, or else to some movement of the head or person, or of the object looked at, by which the mind is enabled, by a comparison of the different aspects of the same body so presented to it, to infer the condition of solidity.

It is scarcely needful to add that the possession of two eyes, in accordance with a general law of bilateral symmetry, widens the horizontal extent of our visual field by several degrees, and is an incidental advantage in the event of one eye being destroyed.

c. Apparent Position of Objects, and their Real Position in Space.—Each eye tells us of the *apparent position* of external objects in its own visual field, that is, of their linear direction from the eye, and of their relative or angular distances from each other upwards, downwards, sideways, or obliquely; and one eye gives the information as truly, and often—as in laying a cannon, or taking aim with a rifle, or making observations with a level, a theodolite, or a quadrant—even more serviceably than two.

But in estimating the *real position* of objects by sight, their depth in space, or distance behind one another, has also to be taken into account; and for near objects this is, to a certain extent, done through a stereoscopic action of the two eyes, just as in the case of our judging of solidity. The third dimension in space—which is itself commensurable to the eye only by reason of the visible objects dispersed in it,—is in fact recognized exactly in the same way as the third dimension of a solid body; and in regard to distances within the range of the binocular parallax, just as we appreciate the cubical form of a solid block of marble, so we judge of the relative position, as to *depth*, of the figures of the group or the limbs of the individual figures, ultimately sculptured from it. So, too, the chessmen on a board stand out from each other, as well as each looks solid itself. It is, indeed, by the use of the two eyes, that these and other solid objects not merely look solid, but are seen separately or apart from each other, like persons in a room, with an atmosphere around them,—just, in fact, as objects appear in a stereoscopic picture.

Beyond this general stereoscopic recognition of the intervention of some depth of space between near objects, we can estimate by practice the relative amount of that space, in other words, their distance behind one another. This is accomplished by looking from one object to another, when the obvious muscular movements which produce convergence of the two eyes, and perhaps also the less noticeable changes of focal adjustment, afford data for an approximate and rapid inference.

The practical advantage of two eyes in estimating the relative depth in space or distances of near objects, is shown in the common experiment of attempting to thread a needle sideways, at arm's length or thereabouts, with one eye shut. This can be accomplished only with practice, and usually by aid of some lateral movements of the head or hands, which furnish to the single eye a double aspect of the needle and thread, from a consideration of which their relative distances or depth in space is estimated by the mind. It is partly in this way, too, that we judge of the real positions of objects beyond the range of the binocular parallax, in which case no stereoscopic phenomena are observed, and no convergence and often no focal adjustment of the eyes is needed. But here we also take into account the effect of different distances on the apparent size of objects; the changes in distinctness of outline and of colour due to aerial perspective; the way in which one set of objects may intercept or be intercepted by others; and, lastly, the effects of linear and plane perspective, and especially the perspective lines and planes of long receding objects or rows of similar objects, and of the surfaces on which they stand.

d. The Apparent and Real Motions of Objects.—The movements of any object immediately perceptible to a single eye, are movements across the field of vision, upwards, downwards, sideways, or obliquely, in a straight or curved course; for direct movements from or towards the very centre of the eye are not immediately perceived. In the former cases, the movement is perceived because the image of the moving object has a motion across the retinal surface; in the latter case no movement is observed, because the image has no motion across the retina. Hence, too, it follows that whatever be the actual movement of a body in space, whether it be in a plane at right angles to the axis of the eye, or in some plane more or less oblique to that axis, its apparent movement from one point in the visual field to another, or its so-called *angular motion*, is the only one immediately recognizable by vision. This motion is named angular because its extent is measured by the angle formed in the eye, by two lines drawn through the eyeball, one from the starting point of the movement, and the other from its point of cessation. In shooting birds on the wing, this angular motion is all that is attended to, and one eye is better than two to observe it. But in estimating the *real* motions of objects from point to point in space, within the range of the binocular parallax, we undoubtedly employ the two eyes stereoscopically, for the same reasons that we estimate the actual positions as to depth of any two fixed points or objects in space. This is exemplified in watching the movements of acrobats or horses in a circus, of cricketers in the field, or of the balls used in that and other games. The necessary changes in the convergence and adjustment of the eyes to keep the moving object in sight, also help us in the determination not only of the real direction, but also of the extent of the movement. Change in size, distinctness of outline and colour, and the passage of the moving body before or behind others, also furnish data on which to form a right conclusion. For objects beyond the range of the binocular parallax, the two eyes furnish no more knowledge than one, and we have to rely entirely on the last-named sources of information.

When the eye itself is moved, the images of all the objects in the field of vision move together over the retina, or this latter may be said to move under or behind the combined images or the general picture; but there is no change in the relative positions of the images of different objects, and therefore there is no apparent movement of one object in regard to any other. The whole scene may shift, but there is no dislocation of its parts. When both eyes are used, there is the same stability in the local disposition of the parts, that is to say, so long as the eyes are harmoniously moved together; and it is truly wonderful how smoothly and accurately the necessary upward and downward, side-to-side, and variously convergent movements of these organs are performed, so as not to be accompanied by double vision or by any apparent oscillation or dancing of the objects around us. Those finer tremors, which are incidental to the smoothest of all muscular movements, and which undoubtedly must influence the globes of the eyes, are rendered of no effect on the steadiness of vision, by the wonderful velocity of the rays of light.

When the entire person is moved through space in one direction, objects appear to move in the opposite direction; and as their angular motion is greater in proportion to their proximity to us, near objects seem to move past us relatively faster than those which are more remote. Both the general and the particular facts just mentioned are constantly observed in railway travelling. When both the observer and the object are moving, compound results ensue; as when two trains meet and pass each other, or when one overtakes another on a neighbouring road. It is by estimating the apparent or angular movements of the heavenly bodies, and analysing what is due to their own and what to the earth's motion—for they are compounded of the two,—that their actual paths or orbits in remote space have been so accurately calculated.

From observations which have been made upon persons born blind, on whom sight has been bestowed by a surgical operation, after they have reached an age at which they could give an account of their sensations, it appears that immediately on the exercise of vision, they perceive light, colour, and the apparent shapes of objects correctly enough. Moreover, there is no evidence to show that, even at the earliest moment of sight, they see objects double; and hence we may conclude that from the very first the eyes properly converge towards any object, and the optical conditions of single vision and also of stereoscopic or solid vision are at once fulfilled. In fact, a cube is at once distinguished by the eye from a sphere or pyramid, and a cat from a dog; but it requires some practice to harmonize the respective visual impressions made by such objects with those already produced by them through the sense of touch. There is no inconsistency between the two senses, and from the very first there is no inversion as to form or position; but experience alone can correctly associate the particular impressions produced by two such different senses,—the one operating by actual contact with objects, the other by the intermediation of luminous rays emitted by or reflected from those objects, and crossing by refraction in the eye. Persons to whom the gift of sight has thus been suddenly imparted have at first to feel an object as well as look at it, to be sure what it is; but very soon they know it by the sight alone. Further and more minute observations are needed to determine to what extent the idea of the outness of visible objects is primitive or innate, or to what extent it may be the result of a rapidly-formed inference. Certain it is that the retinal images are never seen as if *in* the eye, though all objects are said at first to appear to be at a uniform distance before the eye, or according to some to touch it. It is only after much experience that their actual distances are truly appreciated, and, after much cautious trial and not a few collisions, that walking between them is safely performed. The perception of apparent motion in external objects is probably instantaneous; though real motion, like real distance, must at first be ill understood.

The Eyes of Animals.

In the lowest animals, where no nervous system exists, there can be no sight; and even in many in which nerves have been detected, there is still no visual organ. In these cases, light may have, however, some influence on or attraction for them, if not by virtue of its visible or proper luminous rays, at least through its invisible *heating* and *chemical* rays.

The most rudimentary eye consists merely of a little choroidal pigment attached to the expanded extremity of an optic nerve. Such an organ exists in some of the annelids, or worm tribe. A sense of light, perhaps also of colour, must be the limit of its powers. In the snail tribe there exist little eyes, or *ocelli*, in which a body like a crystalline lens has been detected, but its power of forming any distinct image has not been established. In the cuttlefishes, the eye is, however, very highly and curiously organized, approaching in many of its characters the eye of vertebrate animals.

In the lower crustacea, and in the spiders and scorpions, *simple eyes*, or ocelli, possessing in the most perfect examples a cornea, lens, vitreous humour, choroid, and expanded retina, exist either in pairs or clusters. Many of the perfect insects also, as the bees for example, have such simple eyes, which appear in all cases to be suited for near vision. But most insects, in the perfect or imago state, as well as the crabs and lobsters, have also very remarkable *compound eyes*, which consist of aggregations of microscopic conical tubuli, each containing choroidal pigment, and a filament of the optic nerve. Each tubule is covered over by a proper little corneal facet, or there is a corneal covering, common to them all. The number of these tubuli in the compound eyes of certain creatures is well-nigh incredible, —amounting to 5,000 in the lobster, 8,000 in the common house-fly, 12,500 in one of the dragon-flies, and even as many as 25,000 in the mordella, a small species of beetle.

In the vertebrata the eyes, invariably two in number, are constructed after the same plan as the human eye; but their size, position, form, and component parts are singularly modified in different animals, to suit their different conditions of existence and of sight. Two general facts only can be alluded to here; namely, first, that in the eyes of fishes the cornea is remarkably flat, a form which renders it less liable to injury, less likely to produce disturbing undulations in the adjacent water, and of less consequence than one might at first suppose as to the refractive power of the eye, inasmuch as the density and refractive index of the cornea and aqueous humour is so little above that of water. Such defect as there is, is marvellously compensated for by a denser and completely spherical lens, which is much more powerfully refractive than a double-convex one. The aquatic mammalia, as the seal and whale, also have a flattish cornea. The second general fact is that in creatures living in the air and possessing the most remarkable powers of sight, viz., the eagles and vultures, the cornea, the refractive influence of which is great in air, is much more convex than it is in man, whilst the crystalline lens is merely doubly convex.

Concluding Remarks on the Eye and Sight.

Whether we consider the complicated and delicate structure of the eye; its wonderful and practically perfect adaptation as an optical instrument to all the pre-existing laws of light,—being suited alike to receive and use this agent as it comes through water or through air, and being self-corrective as to the errors to which common lenses are liable; the peculiar physiological endowments of the retina, optic nerve, and optic sensorial ganglia; the outward projection of their completed sensations, and all its important consequences in reference to the utility of vision; the adaptive power of the eye to such variable conditions of luminous intensity, distance, direction, and motion of visible objects; the mode in which the two eyes co-operate to subserve the most essential purposes of single and solid vision; and, lastly, the manner in which, amidst all its actions and its wear, the nutrition of this wonderful organ is incessantly provided for;—there cannot be a more striking illustration or cumulative proof in the animal economy, of the wisdom and beneficence of the Creator.

Nor is it possible to find a happier example of that class of facts in organic nature, which, in spite of certain bold generalizations, seem to confirm the doctrine that distinct and direct interpositions of creative power have from time to time been manifested in the history of the globe on which we live. For, though man may imagine, on tracing out the long gradations of animal forms, and arranging them in series according to their gradual transitions of outward shape or plan of internal structure, that he has discovered a force of development, adequate to beget, by metamorphosis on metamorphosis, through countless ages and endless mutations of primitive organic impulse and external physical conditions, the whole range of animal species, from a monad to a man; yet he can hardly comprehend how either a nerve or a sensorium devoted to common sensation, could be changed by any inherent impulse or the action of light into a retina, optic nerve, and optic sensorium; nor how any mutual endeavours of light and organic matter could, unaided by a special exercise and determination of creative force,—produce an organic refractive apparatus in front of the retinal expansion of that nervous arrangement.

Like the ear, the eye ministers directly only to its own functions. Like the ear, it conveys to us a special knowledge of external nature, altogether unattainable through any other channel; for though many of the visual impressions, as of matter, form, size, number, space, distance, and motion, are but extensions of the notions derivable from touch, and some of them require even to be tested by this latter, narrower, but after all surer, sense, still the vast range, rapidity, and accuracy of sight, endow it with a speciality of power, and in reference to colour or light itself—the most spiritual thing we know,—the eye, of course, is its only inlet to our perception.

It is remarkable, that of the five senses, the highest should, in regard to its revelations of external nature, have more points of contact with the lowest, than with the intermediate senses in rank; for sight and touch go hand in hand, whilst with hearing, smell and taste, seeing has much fewer relations.

Less social, or less conducive to the purposes of social intercourse, than hearing, sight is of superior necessity to the individual, and even to society at large. Incomparably above the other senses in contributing to our knowledge of outward things, it is infinitely more powerful than them all for evil or for good. According to the motives by which it is employed, it serves the most intensely selfish, or the most beneficent ends. It may excite the desires and passions, and aid in the commission of crime; but its special office is to feed the intellect, to be the observatory of the mind, and to minister to the highest executive powers of the human will and hand.

In ordinary life, sight is the incessant source of the most useful and necessary knowledge and the most delightful pleasures; it is the constant guide in our every-day duties and enjoyments; and without it writing and printing would be useless, nay, unknown sources of information. In the arts and manufactures it is indispensable; and especially as exercised in sculpture and in painting, it detects and perpetuates the beautiful in form and colour; and thus preserves and recalls the memories of the past.

But its loftiest triumphs are not in every-day observation and use, nor yet in rendering possible the perception of so many beauties, and the realizations of our artistic genius; for it is essentially the *scientific sense.* It investigates, separates, and mensurates everything in nature. Aided by the microscope and telescope, it detects the globules of apparently homogeneous blood, and the stars of distant and otherwise invisible systems, and so reveals to us the processes of formative action close at hand, and millions of miles away. Nothing in earth, ocean, or air, may escape its ken. It unravels all organic forms and tissues, and even scans and interprets its own marvellous structure. It analyzes all inorganic compounds, first determining the value of its own tests. By aid of the balance, rule, angle, and circle, it weighs and measures universal matter, force, motion, and space; and by endless metrical instruments, whose elaborate construction and delicate operations it superintends and reads—such as chronometers, electrometers, the mariner's compass, quadrants, theodolites, photometers, thermometers, barometers, and the rest,—it gives an otherwise unattainable exactitude to all discoveries, which renders them fit subjects of scientific induction, and the safe bases of the highest generalizations. Even sound, the object of another sense, yields the secrets of its physical cause and laws to the detective powers, not of the ear, but of the eye.

In the domain of optics, the eye reigns alone and supreme, unravelling, by its keen perceptions, the beautiful and mysterious qualities and laws of light. Provided with a surface more sensitive than the iodized paper or plate, ever ready for immediate and repeated use without impairment or imperfection, it is the model camera, to which all nature sits as in a photographic studio, in which she pictures herself with unsurpassable lucidity and truth.

The penetrating character, the wide-stretching powers, and the reliability of sight, are well exemplified in such terms as insight, scope, and evidence, derived from the English, Greek, and Latin forms of the verb to see, and applied to the operation of our intellect, our powers of observation, and our determination of truth; whilst the practical fidelity of sight, which is our finest standard or test in all physical matters, is asserted in the common phrase of "seeing is believing." That "the light of the body is the eye" we read in Scripture; and in such expressions as the light of truth, and civilization, and Christianity, and in such words as circumspection, introvision, and foresight, we recognize moral similitudes drawn from comparisons with the actions of our visual organs. Finally, in our humble strivings to designate the attributes of the Creator, we twice borrow from language founded on the operation of this most searching of our senses, the comprehensive designation of "an All-seeing Providence."

No. 9.—The Microscopic Structure of the Textures.

◆

Nearly two centuries since, Malphigi, and afterwards Leeuwenhoek—the first an Italian and the second a Dutch anatomist,—began the microscopic examination of the textures of the body; but it is only within the last thirty years that all the tissues and organs have been systematically examined. Even yet, there are many points of detail, especially concerning the origin or formation of the tissues, about which differences of statement and opinion exist.

In the following description, attention should be constantly directed to the exquisite adaptation of the mechanical structure and vital properties of the different textures to their special uses.

All the figures in this diagram are much enlarged, most of them very much so, *i.e.*, from 800 to 3,500 linear diameters; and, as the elementary microscopic constituents of the tissues, when thus highly magnified, are, in nearly all cases, transparent and colourless, or very faintly coloured, it must be understood that the tints employed to distinguish them are somewhat exaggerated.

The Origin, Formation, and Structure of Vegetable Textures.

Figures 1 to 7.

Fig. 1.—Small portion of the *yeast-plant*, or submerged form of the fungus named *Penicilium glaucum.*

Fig. 2.—Fragments of an algaceous plant name *Hæmatococcus binalis,* allied to the red snow-plant of the Arctic regions.

Fig. 3.—Section of a portion of the bulb of the onion.

Fig. 4.—*a*, A vegetable cell from the potato, filled with starch-grains; *b*, a separate starch-grain, more highly magnified.

Fig. 5.—Portion of the hard substance of a pear.

Fig. 6.—Fragment of the common rush, showing star-shaped cells joined together.

Fig. 7.—Section of a part of the stem of a reed: *a*, the pith; *b*, the outer covering, or cuticle; *c*, annular duct; *d*, spiral duct; *e*, dotted duct; and *f*, woody fibres.

As illustrated in the preceding figures, all vegetable tissues are formed of or from minute vesicular bodies called *cells*, which cohere together by more or less *intercellular substance*, sometimes called *blastema* (from βλαστος, a germ). All plants originate in a single cell of this kind; and, in proportion as the plant grows, the cells multiply, until, in the larger species, such as shrubs and trees, myriads of cells are built up into one individual plant. At an early period of their development, as in young plants, or in the growing parts of plants (see fig. 3), these cells consist of an homogeneous envelope, or *cell-wall*, lined by a softer formative layer, called the *primordial utricle*, inclosing certain fluid *cell-contents*, and containing at some point a distinct roundish body, called a *nucleus*, within which again are one or two still smaller dot-like bodies, named *nucleoli*. The nucleus, from the presence of which the cells are termed *nucleated cells*, is of very great importance, and is regarded as a sort of nutritive centre, or centre of growth. In the multiplication of the cells under typical conditions in the growing plant, this nucleus, whose nucleolus has first doubled, divides into two parts, each having its own nucleolus, and each forming around itself a new cell; so that the new cells, as a rule, arise by a progressive or continual "*endogenous*" growth within the pre-existing cells. This is exemplified in fig. 2. As the cells reach maturity, the nuclei frequently disappear.

The forms of these uncleated cells undergo great metamorphoses, and they vary much in shape, according to the tissue which they ultimately combine to produce. The fundamental form, such as is seen in the simplest fungi, fig. 1, and algæ, fig. 2, or in the primitive germ-cell of the embryos of the higher plants, is a spheroidal, or somewhat elongated vesicle.

By successive multiplication in a linear direction, accompanied with slight changes in form, beaded or jointed threads are produced; and, by lateral sproutings, branched filaments are developed, as in the yeast-plant, fig. 1. By successive subdivision, pairs or aggregated clusters of coherent cells are formed, such as compose the Hæmato-coccus, fig. 2. Indeed, all the tissues, even of the highest of the *cryptogamic*, or *flowerless* plants, such as the fungi, algæ, lichens, and mosses, are formed by similar, or other very simple changes in the size, form, and contents of multiplying and coherent cells. Hence they have been name *cellular* plants.

The tissues of the higher *phanerogamic*, or *flowering* plants, much more complex in structure, are also developed from cells. These, however, undergo more striking changes; for they not only become altered in size and shape, and in the character of their walls and cell-contents, but they are converted, in some cases, into solid *fibres*, called woody or ligneous fibres, and in other cases, coalesce, so as to form open *tubes*, called *ducts* or *vessels*. Hence the flowering plants have been named *vascular* plants.

Changes in size and form are illustrated in the rapidly-growing, coherent, compressed, and neatly-fitted polyhedral cells, with transparent walls and cell-contents, which compose the succulent part of the bulb of the onion, fig. 3. In some of the cells the nuclei exist; in others they have disappeared.

Changes in the cell-contents, which, at first are fluid, transparent, and homogeneous or faintly granular, are illustrated in the large cells of the potato, fig. 4, *a*, which become closely packed with the little bodies called *starch-grains*, the pale nucleus being nearly concealed by them. The peculiar structure of starch-grains, with their concentric lines surrounding a usually excentric point, and indicating a laminated arrangement, is shown at *b*. Besides starch, which is in all cases deposited in cells, the cell-contents may be mucilaginous fluid, gum, sugar, green colouring matter or chlorophyl, as in leaves, other colouring matters, as in flowers, essential oils, or resins.

Changes by a fixed *ligneous deposit* on the internal surface of the cell-walls, are exemplified in the *ligneous cells* of the firm substance of the centre of the pear, fig. 5, in which the deposit is arranged in concentric laminæ, but so as to leave little radiating pores passing through it.

The branching out of cells, and the methodical meeting of their branches, so as to form a network of cells with very large intercellular spaces, is shown in the peculiar *stellate cellular tissue* from the pith of the common rush, fig. 6.

The mode in which the cells become elongated or fusiform, and then blocked up with lignine, or woody substance, so as to form overlapping, and often extremely hard and durable, *woody fibres*, is shown at *f*, in fig. 7, which represents a section of the stem of a growing reed. This figure, moreover, affords a useful illustration of a great variety of changes necessary to take place in adjoining cells, for the formation of the different vegetable textures, especially the various kinds of *vascular tissue*. Thus, *a* shows the elongated, compressed, alternating, loosely-fitted, and slightly coherent cells of the *pith*, having colourless contents or becoming dry and empty; *b* shows the cells of the *cuticle* covering the surface of the stem, flattened, thin-walled, neatly-fitted, and firmly coherent, and containing granules of green colouring matter; *c c* are rows of elongated cells, in different stages of coalescence, by which, when the double ends or partitions are absorbed a perfect tube or *vessel* is produced; *d* is a vessel similarly formed, but having spirally-arranged fibres of ligneous matter deposited on the interior of its walls, and hence called a *spiral vessel* or *duct; e* is another sort of vessel, originating in the same way, but having the internal ligneous deposit so arranged as to leave certain spots uncovered, thereby producing what is called a *dotted vessel* or *duct; f*, as already stated, refers to the elongated solidified cells which form the fusiform *woody fibres*.

In contemplating the multiplication, growth, and metamorphosis of these microscopic nucleated vegetable cells, each possessing special forms and properties, but all co-operating to one common end,—the production of an individual plant, with its specific characters, its many different parts and its various component textures, attaching itself to the soil, absorbing material by its roots and converting this into nutriment in its interior, respiring by its leaves, storing up its secretions in special cells, manifesting in certain organs a feeble kind of vital contractility, and developing flowers, fruit, and seed, capable of reproducing its own likeness,—we are presented with but a glimpse of a picture no less comprehensive than the formation of the innumerable individuals of the vegetable world, with all their respective manifestations of plant-life. For by such simple and inimitable means as the multiplication and infinitely varied modification of living vegetable cells, are realized all the wonders of this department of the organic world.

The Origin and Formation of Animal Textures.

Figures 8 to 15.

Fig. 8.—A *white* and a *red corpuscle* of the human *blood*, magnified about 3,500 diameters.

Fig. 9.—A branched *nerve-vesicle*, or *nerve-cell*, from the grey substance of the human brain.

Fig. 10.—A minute portion of *cartilage*, showing the cells lying in its substance.

Fig. 11.—Cells of different forms found in the growing *areolar* or *connective tissue.*

Fig. 12.—Cells found in the growing yellow *elastic tissue.*

Fig. 13.—A ramified *pigment-cell*, containing black colouring matter, from the skin of the tadpole.

Fig. 14.—Portions of two fibres of *voluntary muscle*, in different stages of development.

Fig. 15.—Ramified cells, coalescing, and opening into one another, to form new *capillary blood-vessels.*

The tissues of animals, as might be anticipated from their higher functional capacities, are far more diverse and complicated than those of plants, and it is much more difficult to trace their exact mode of formation. The discovery of the vegetable cell as the source of all vegetable tissues, led to the supposition that the animal textures were likewise derived from metamorphosed nucleated cells; and since the earliest recognizable condition of the germs of all, even the highest animals, is a clear, transparent, sphericle vesicle, containing a nucleus—in other words a nucleated cell,—it is certainly true that all the tissues of the future animal are remotely traceable to the formative influences or forces which reside in, or are associated with, such an *animal nucleated cell;* though, as will hereafter appear, all the animal tissues may not directly and solely result from the metamorphoses of such aggregated cells themselves.

The typical animal nucleated cell is a round or roundish vesicle of microscopic dimensions, which, like the vegetable cell, is composed of the following parts: a *cell-wall*, or *envelope*, composed of homogeneous membrane; within this, in some cases, a soft growing layer, thought to represent the *primordial utricle; cell-contents*, fluid, or semi-fluid and granular; a smaller vesicular body within, called a *nucleus;* and within this, one or two *nucleoli.* Lastly, these cells are either suspended in an *intercellular fluid*, or held together by a firmer *intercellular substance*, or *blastema*, which may itself be variously organized.

The principal forms into which these cells are modified in the growing or perfected tissues of the human body, are represented in the preceding figs. 8 to 15; and also in many of the succeeding figures, especially figs. 71 to 81.

The cell may, without deviation from the spheroidal form, be isolated and suspended in a fluid blastema, as in the case of the lymph corpuscle, and the *white blood-corpuscle*, fig. 8; or, under the same conditions, it, or its nucleus only, according to some authorities, may change in form, and its contents be modified in colour and chemical composition, so as to produce the flattened *red blood-corpuscle*, also shown in fig. 8.

The nucleated cells, growing very large and becoming filled with a fluid fat, constitute the cells of *adipose tissue*, fig. 22.

Still further changes in the form, contents, chemical composition, and mode of aggregation of the nucleated cell are illustrated in the characters of the epithelial and epidermic tissues represented in figs. 71 to 81, and described in their proper order hereafter.

The cell, lying in a soft granular blastema, and acquiring peculiar coloured contents, may send off fine processes or *fibres*, which join other associated cells or fibres, as in the case of the *ganglionic vesicles* or *nerve-cells* of the grey substance of the brain, fig. 9.

The cells, multiplying by successive subdivision of their nuclei and growth of new cells around these, may have their walls thickened by internal deposit, and their intercellular blastema also increased, solidified, and blended with the cell-walls, so as to form a firm elastic substance, such as *cartilage*, fig. 10. Or the intermediate uniting substance may become more or less split into fibres, as in *fibro-cartilage*, fig. 24; or both the cells and the matrix or blastema may be charged with earthy matter, so as to form the *preliminary state of the osseous tissue.*

Another metamorphosis which has been described, consists in the gradual lengthening out, branching, and subsequent splitting of the substance of the cells into *fibres*, as represented occurring in three cells, one *round*, one *caudate*, and the third *fibrillated*, taken from newly-forming *areolar* or *connective tissue*, fig. 11. Similar changes are shown in two ramified cells found in the growing *yellow elastic tissue*, fig. 12. The fibres of the areolar tissue are by some, however, believed to be developed by a process of *fibrillation in the blastema* lying between these fusiform and ramified cells, which are themselves supposed to anastomose together and form the fine elastic fibres which are always found intermixed with the areolar tissue (see fig. 18).

A remarkable illustration of branching cells is seen in the *ramified pigment-cells*, charged with granules of black colouring matter, found in the skin of the frog or tadpole, fig. 13.

Fibrous structures much more highly organised than those already alluded to, and endowed with higher vital properties, such as the *muscular* and *nervous fibres*, are also said to be traceable to the coalescence and metamorphosis of nucleated cells. In the case of *involuntary muscular fibre*, figs. 36, 37, rows of cells or celli-nuclei unite and lengthen out, and then the peculiar soft *contractile* matter is deposited upon or within them. In the *voluntary muscular fibre*, fig. 31, the proper contractile substance deposited in the coalesced cells around the rows of nuclei, as shown in two portions of fibre in different stages of development, in fig. 14, gradually assumes a special arrangement, by which it may be split into fine *fibrillæ*, fig. 30, whose component particles, placed side by side, fig. 32, produce characteristic transverse lines or striæ, and may also separate into transverse discs. Around the group of fibrillæ constituting a single fibre, a thin, transparent, homogeneous elastic tubular sheath, seen in fig. 31, and called the *sarco-lemma*, is then deposited; and in the mean time the nuclei disappear.

The *nerve-fibres*, the conductors of all sensational and motor impressions, figs. 39 and 43, are described as being formed in a somewhat similar way; and we have already seen, in fig. 9, that the grey central parts, or seats of power in the brain and spinal cord, are composed essentially of nucleated cells.

Lastly, the nucleated cell may ramify, its branches may unite with those of other neighbouring cells, and the whole becoming hollowed out, form a net-work of *tubes* or *vessels*, such as the finest *lymphatic vessels* and the newly-forming *capillary blood-vessels*, fig. 15, which, uniting with and opening into previously-formed vessels, allow the lymph or blood to flow into and along them. By enlarging and acquiring additional coats, also developed from newly-formed cells, a capillary vessel becomes an *artery* or a *vein*.

The heart itself is at first a mass of aggregated nucleated cells, of which the outer ones are arranged and metamorphosed into the muscular walls and outer and inner tunics of the heart, whilst the central ones soften down into a liquid mass, which is blood. The largest vessels perhaps originate in a similar way. It is also through the agency of nucleated cells that the ducts of glands, with their *epithelial cells* resting on a *structureless basement membrane*, are hollowed out of branching solid streaks which shoot out into a granular mass of blastema, afterwards converted, by the development of fresh cells, into the proper substance and vessels of the gland.

By these varied changes in the cells themselves, in their mode of combination, in their contents, in their nuclei, and in the intercellular blastema which unites them, all the tissues of the animal body are produced. New cells continually arising in the process of growth, are, many of them, as in cartilage, the result of "endogenous" formation in the *interior* of old cells, as occurs in plants, either by the subdivision of the nucleus and the formation of a new cell upon each half, or by a process of fissuring of the parent cell and its nucleus also; but in other cases, new cells may arise in the blastema, *outside* the old cells, or *interstitially*, usually by the formation of what are called *free nuclei*, around or upon which cell-walls are subsequently formed. In the reparation of tissues, too, fibres may be formed by the fibrillation of a blastema without the intervention of cells; but still nuclei appear in the blastema, remain for a time visible, and then disappear. Hence it would seem that the nuclei, as already stated in speaking of the development of the vegetable cell, are of great importance. They are indeed regarded as the nutritive centres of the cells, either preceding their formation, or leading to it by their subdivision, and fading away when the cells or the blastema have reached their final expression as to form. In structure, the free nuclei appear at first to be nothing but an aggregation of *granules* or *molecules*, into which the living blastema, analogous to the liquor sanguinis, is apt, as it were, to concrete. In this point of view, the molecules or granules may be said to precede or have an earlier significance than these nuclei, and again, as evidently the blastema must precede the molecules. But living blastema, itself capable of organization, is formed, so far as we are acquainted with the mysterious circle of animal development, only under the influence of nucleated *germ-cells*—themselves the product of a pre-existing organ or organic cell; so that, in fine, we rest, in the animal as in the vegetable world, in the little vitalized and formative sphere—the nucleated cell,—as the starting-point of all individual being.

The entire process of the formation of animals of all kinds and species, from the animalcule up to man, consists, then, in the growth of nucleated cells, or of parts formed under the influence or guidance of such cells. All the specific forms, the individual characters, and the hereditary likenesses and peculiarities of men and animals, all their internal organs, and all the tissues of which their bodies are composed, are the result of a regular and predetermined differentiation of elementary constituents, whether cells, nuclei, or blastema, which are the progressive offspring of a single parent germ-cell.

The results arrived at by such apparently simple means are even more miraculous than in the case of plants; for, in animals, in addition to the nice mechanical adaptations, the chemical forces, the formative, nutritive, and reproductive powers, and the occasional contractility observed in metamorphosed vegetable cells, we have to contemplate the far more highly-strung contractility of the muscular tissue, and the inscrutable association of sensibility, consciousness, and emotional, rational, and volitional functions, with material instruments also composed of or by highly organized and metamorphosed nucleated cells.

The Structure of the Animal Textures.

The Areolar-connective, Fibrous-connective, and Elastic Tissues.

Figures 16 to 21.

Fig. 16.—Interlacing bundles of wavy filaments of the *areolar* form of *connective* tissue, or *cellular* tissue.

The *connective* tissue, so often mentioned in the descriptions of the preceding diagrams, as its name implies, serves to connect the several organs and parts of organs together, supports their nerves, blood-vessels, or ducts, and, at the same time, by its extensibility, permits such displacements as are necessary to their several functions. It consists, in most situations, of a loose, moist, and extensible web, composed of soft threads and laminæ, having interspaces call *cells* or *areolæ* between them; hence its other names, *cellular* and *areolar*. These areolæ communicate through the body generally, and are the spaces in which the fat or adipose tissue is lodged, and in which the fluid collects in general dropsy. Beneath certain membranes the areolar tissue is called *subcutaneous*, *submucous*, *subserous*, or *subsynovial*. Here it facilitates the necessary changes in the position or degree of distention of such membranes; and, besides that, assuming a more compact or condensed condition, it forms the undermost layer of those membranes themselves.

The finest laminæ and bundles of the connective tissue are composed of soft transparent filaments, as fine as $\frac{1}{15000}$th, or even $\frac{1}{25000}$th of an inch in diameter, held together by a little homogeneous matter. These filaments have never been seen to divide or branch; they are wavy in their direction, and the bundles in which they are collected interlace—arrangements all well calculated to bestow the necessary flexibility and extensibility on this common but important tissue. Its elasticity or resiliency is provided for by the copious intermixture of excessively *fine elastic fibres*, belonging to the elastic tissue. In the subpleural areolar tissue on the lung, and in the submucous tissue of the stomach and intestines, where very great elasticity is required, these elastic fibres are larger and more abundant.

Fig. 17.—Parallel wavy filaments of the *fibrous form of connective tissue.*

The constituent elements of this tissue are like those of the areolar tissue, viz., the white filaments of connective tissue, with intermixed fine elastic fibres; but their arrangement is in close and parallel bundles, having a shiny appearance and marked with faint cross striæ, instead of being open and interlaced. Hence they form glistening, tough, resisting, and inextensible tissues, instead of loose extensible ones. The fibrous tissue is found in the body under two forms; viz. first, as *fibrous membranes*, which consist of straight bundles of the tissue, intersecting each other obliquely in all directions, and held firmly together by cellular tissue, as seen in the periosteum, the dura mater, the fibrous tissues of the eye, in certain broad ligaments and tendinous expansions, and in the strong parts of the fascia; and secondly, as roundish or flattish *fibrous cords*, as in certain ligaments and tendons, in which the bundles themselves are aggregated together in a parallel manner. Whilst the fibrous membranes bind down, support, and protect other parts, the ligaments and tendons, which are very flexible, but strong and unyielding, give security to the joints, and trans mit, without loss of power from stretching, the contractile force of the muscles to the bones. The ligaments and tendons are so strong, that in many cases of violence the bones give way first.

Neither the areolar nor the fibrous tissues are very vascular, nor are they supplied with many nerves. The numerous vessels found in the periosteum, for example, are passing to or from the bone, and the nerves found in the areolar tissue are usually those proceeding to other structures. Tendons and ligaments are insensible in health, except to the effects of over-stretching; but when inflamed, they become very painful, proving the existence of nerves in them.

Fig. 18.—A single filament of connective tissue, to which acetic acid has been added.

The addition of acetic acid to the connective filaments makes them swell up to an enormous size and become quite soft and transparent, whilst the fine elastic fibres, which are not similarly affected, become remarkably well defined. In this case the latter are seen as dark lines running upon, and even embracing the connective filament; in the fibrous membranes they form a network of branching fibres, and in the tendons they lie between the pale white filaments, and are connected with small elongated nuclei.

The connective tissue, in all its situations and forms, is almost entirely converted into gelatine on being boiled.

Figs. 19, 20, 21.—*Elastic tissue* under three different forms.

This tissue is not only extensible, but, as its name implies, *elastic*, that is to say, it retracts like a piece of vulcanized india-rubber, after it has been put on the stretch. Nevertheless, it does not possess any contractility or active power of shortening itself, like the muscular fibre.

As already mentioned, it exists in form of very fine dark fibres, mixed up with the fibrous and areolar forms of the connective tissues, in larger or smaller quantity, according to the elasticity required in different situations. It exists in its purest and most developed form, and of a yellowish colour, in the yellow elastic ligaments of the vertebral column, p. 14, which are composed almost entirely of large clear fibres, with dark outlines, measuring from $\frac{1}{7000}$th to $\frac{1}{4000}$th of an inch in diameter. These fibres do not run quite parallel; they frequently branch and anastomose together, and leave, when torn, abrupt and curled ends. It exists in the same form, but with finer fibres, in the true vocal cords and in some other ligaments of the larynx, and also in the coats of the arteries and veins. In the internal coat of the arteries it is present in a peculiar form, its component fibres being flattened out, and joined very frequently together, so as to form not merely a close network, as represented in fig. 19, taken from the pulmonary artery of a horse, but a *fenestrated* or *perforated membrane*, such as is shown in fig. 20, from the carotid artery of the same animal. The posterior layer of the cornea, and the capsule of the crystalline lens, appear to be composed of similar material blended into an *homogeneous membrane*.

The elastic tissue is neither very vascular nor sensitive. It resists the action of diluted acids, and yields, on boiling, a substance different from gelatine.

The Adipose Tissue.

Figure 22.

Fig. 22.—Cells of the *adipose* or *fatty* tissue, supported by filaments of connective tissue.

The fat of the body, at the natural temperature, is an oily fluid, contained within roundish, oval, or somewhat compressed vesicles, which are the largest nucleated cells in the body, measuring from $\frac{1}{600}$th to $\frac{1}{300}$th of an inch in diameter. When the cells are well filled, as in health, the nuclei are invisible, nothing but the pale yellow highly refractive oily contents being seen; but during the development of the tissue, or in emaciation, when the cells become shrivelled, or after steeping in water, the nuclei become apparent. These fat-cells are gathered into clusters, several of which unite to form the smaller and larger lobular masses recognizable by the naked eye. The lobules are held together by connective tissue, in the areolæ of which they lie, and also by special blood-vessels, which end in a beautiful network of capillaries upon the outside of the cells. The fluid fat within the cells, which escapes on the application of heat, or when the tissue dries, consists of olein containing a little margarin in solution. When the body becomes cold, small crystals of fat, probably margarin, are seen lying in some of the cells.

The fat pads or fills up certain interspaces between and around the various organs of the body, especially those of the abdomen; it also accumulates in the hollows around the joints and between the muscles, and spreads over the general surface of the body beneath the skin, giving roundness to the contours of the human form, and acting as a powerful non-conductor for the retention of heat within the frame. Lastly, it is found within the bones, where it forms the marrow. This *marrow* or *medulla* is indeed composed of delicate adipose cells, a few proper marrow-cells, and a very small proportion of areolar filaments. It is highly vascular. In the long bones it is yellowish; in the short ones, reddish and less fat.

It is remarkable that fat is never found within the cranium, where its alternate deposition and absorption, or its great accumulation, would interfere with the brain and its functions; nor yet in the lungs, with whose action it would also interfere; nor yet in the eyelids, whose freedom and rapidity of movement would be impeded by it.

The adipose tissue constitutes a store of fatty nutriment, which is always available for the purposes of the system when required. Fatty matter, it will be remembered, exists abundantly in the chyle (p. 79), also in the blood, and, in larger or smaller quantity, in nearly every tissue of the body, but especially in the nervous tissue, and in certain secretions, as milk and bile. Like other hydro-carbons, fat is, moreover, always being consumed or combined with oxygen in respiration to afford animal heat (p. 102). The excess of fat in the blood, not required for the nutrition of the tissues or for the purposes of secretion or respiration, is removed from the circulation and locked up, as it were, in the cells of the adipose tissue, from which, when necessary, owing to illness, prolonged abstinence from food, or interference with the digestive process, it can be retaken up into the impoverished blood.

In healthy children, in whom nutrition and growth are active, there is always a store of deposited fat ready for use. Fat is more abundant in the female than in the male. It becomes excessive in those who eat and sleep too much, and take but little exercise, whilst it is reduced by the opposite conditions. The nature of the food and drink has also much influence in the production of fat. There are, however, individual, family, and even national peculiarities in this respect, independent of habits and customs. In hybernating animals, fat is stored up in the system previously to the coming of winter, during which it protects them from cold, and is slowly used in respiration, whilst they cannot take food.

Cartilage and Fibro-Cartilage.

Figures 23 and 24.

Fig. 23.—A minute piece of *pure cartilage* from a joint, showing little corpuscles embedded in a compact substance.

Articular cartilage consists of a firm, opalescent, homogeneous, or slightly granular substance, called the *matrix*, in which are little spaces or *lacunæ*, containing the bodies called *cartilage corpuscles*. These are the remains of nucleated cells, the nuclei of which are very distinct, usually measuring from $\frac{1}{2400}$th to $\frac{1}{4000}$th of an inch. Except superficially, where they are flattened and parallel with the free surface of the cartilage, the corpuscles are arranged perpendicularly, and the substance of the cartilage tears or breaks most easily in that direction. In the rib-cartilages, and in those of the larynx, air-tubes, and nose, the matrix is indistinctly fibrous, and the corpuscles somewhat larger; the larynx and rib-cartilages become bony in old age. The firmness, strength, and elasticity of cartilage make it so useful in the animal frame. The smoothness of its free surface fits it for the joints.

Fig. 24.—*Fibro-cartilage*, consisting of cartilage-corpuscles lying in a fibrous matrix.

This tissue, the structure of which is characterized by its distinctly fibrous matrix, the proportion of which varies in different cases, is softer and more flexible than cartilage. It is found in the intervertebral ligaments (p. 16), the interosseous ligaments (p. 14), the interarticular cartilages (p. 19), and in some other situations.

The soft cartilages of the ear, eyelid, and epiglottis are composed of a yellow fibro-cartilage, the fibres of which resemble the elastic tissue.

Articular cartilage is quite destitute of vessels, and is nourished by imbibition of fluid, chiefly derived from the vessels of the subjacent bone, but partly also, at the margins, from those of the synovial membrane. The cartilages of the ribs, larynx, and nose, and the fibro-cartilages of the ear, have a distinct investing membrane, called the *peri-chondrium*, which is vascular, and resembles the periosteal covering of the bones. The rib-cartilages have channels in their interior for blood-vessels. Fibro-cartilages are slightly vascular.

Pure cartilage contains 4 parts in 10 of solid matter, which is converted by boiling into *chondrin*, a substance somewhat like gelatine. Fibro-cartilage yields gelatine on being boiled.

The Osseous Tissue or Bone.

Figures 25, 26, 27.

Fig. 25.—An enlarged view of a thin cross-slice of the ulna, showing the cavity in the centre, and the porous character of the surrounding compact bone. The dark portion is shown more highly magnified in the next figure.

Fig. 26.—A small portion of the ulna, showing the smallest *pores* of the bone, and the laminated structure of the hard substance around them.

Fig. 27.—Two pores, with their surrounding *laminæ* still further enlarged, showing the little bodies (here seen dark) called the *corpuscles* or *lacunæ* of bone, with fine lines or *tubuli* radiating from them, called the *canaliculi.*

The dense or *compact* osseous tissue which forms the surface of bones (p. 2) is very thin in the broad and irregular bones, but much thicker in the bones of the roof of the skull, and in the shafts of the long bones of the limbs, where the principal strain upon these takes place. The *spongy* tissue (p. 2), also called the *cancellated* tissue, from the *cells* or *cancelli* in it, forms the greater part of the broad and irregular bones, and of the extremities of the long bones (see diagram No. 2, figs. 5, 7, 8); but in the shafts of the latter it gives way to a central cavity, called the medullary cavity, which contains the *marrow* or *medulla.*

This medullary cavity communicates freely with the cells of the spongy tissue, and from these again there pass into the compact tissue smaller channels, seen as *pores* on the section, fig. 26, called the *canals of Havers*, which, forming a reticulated system of tubes, becoming finer as they approach the surface of the bone, finally open upon it by numerous orifices. These Haversian canals vary from $\frac{1}{2000}$th to $\frac{1}{200}$th of an inch in width.

During life, the medulary cavity, the cancelli, and the largest Haversian canals, contain numerous blood-vessels, arteries, capillaries, and veins, supported by the *adipose tissue* of the marrow (see p. 235). The finest Haversian canals next the surface of the bone are occupied by blood-vessels only, chiefly capillary, which communicate with the vessels of that highly vascular fibrous nutrient membrane covering the bones, called the *periosteum.* In this perfect way the nutrition of bone, which even in its compactest form is a very vascular tissue, is provided for.

The solid matter of the bone, which is the part left after maceration and drying, has everywhere the same very characteristic structure, being arranged in closely-blended *laminæ*, which as shown in figs 26 and 27, are disposed concentrically around the canals of Havers, or correspond with the outline of the cancelli, or run parallel with the surface of the bone, tying together and embracing all the other laminæ. The strength of a tissue so built up will be obvious.

Lying amidst the laminæ, and corresponding in direction with them, are microscopic bodies, or rather cavities, called *lacunæ*, from which numerous exceedingly minute radiating and branching tubuli, called *canaliculi*, pass off through the laminated substance, serving to connect the cavities of the lacunæ with each other, and with the neighbouring Haversian canals. In sections of bone ground very thin, and viewed by transmitted light, the lacunæ and canaliculi appear dark, as in fig. 27; but by reflected light, they are opaque white. This is owing to fine particles which they contain, some of them perhaps accidentally introduced in grinding the section for the microscope. They are undoubtedly little hollows and tubes, which during life allow a nutritive fluid, exuded from the blood in the vessels of the Haversian canals, to permeate even the solid substance of the bone.

This substance consists of animal and earthy matter, the one giving toughness and elasticity, the other firmness and rigidity and strength to the bones. The two constituents are intimately blended together in every part of the bone; for if the former only be removed from any given bone by careful burning, or the latter by maceration in dilute hydrochloric acid, the residual mass in either case retains the shape of the bone,—being hard, dry, and brittle in the one case, but soft, tough, and flexible in the other. The earthy matter, about 66 per cent. of the whole, consists of nearly 50 parts of tribasic phosphate of lime, 10 of carbonate of lime, and the rest of fluoride of calcium, phosphate of magnesia, and common salt. The animal matter, about 33 per cent., is resolvable into gelatine on boiling.

In a softened bone, macerated in acid, a further structure becomes manifest in this animal matter; for it may be torn or separated into *fibres*, which have a reticular arrangement, crossing each other in strata in the several laminæ of the bone, and coursing between the canaliculi and lacunæ. This fibrous structure has been compared to the wavy filaments of areolar tissue, the homogeneous matrix of cartilage, and the fibres of fibro-cartilage, whilst the lacunæ with their canaliculi, are supposed to represent modified nucleated cells, analogous to the branching elastic fibres mixed with the areolar tissue, and to the corpuscles of cartilage and fibro-cartilage. Other cells are found in softened bone, which, as well as the lacunar cells, are regarded as its nutritive centres.

As already stated, bone is very vascular, bleeding very freely when fractured or exposed. Its arteries enter chiefly from the periosteum; but in long bones there is an orifice which admits an artery specially for the marrow: in the femur, two such arteries exist. The veins are large, and have unusually thin coats. Lymphatics are supposed to exist. Small nerves also enter the bones. In the healthy condition the marrow is very feebly sensitive, the periosteum less so, and the bone not at all. When inflamed, all these parts give pain when touched,—of course from the action of nerves passing through them.

When first formed, the internal framework or skeleton is not bony; but, with the exception of the parietal and parts of the frontal and occipital bones, which in their early stage are *membranous*, is composed of solid *cartilage*. This condition reminds us of the permanently cartilaginous state of the vertebrate skeleton in certain fishes, and in the proteus and allied animals. In these temporary membranes or cartilages, ossification sooner or later begins.

In the *intra-membranous ossification*, a fibrous structure mixed with nucleated cells is first saturated with earthy deposit, and so becomes calcified; and then, by subsequent changes in this tissue, cancelli, or Haversian canals, with their surrounding laminæ, lacunæ, and canaliculi, are formed. The process commencing in the cranial membrane at central points, or *centres of ossification*, spreads until the several bones meet at their edges, by which they continue afterwards to grow; thus enabling the brain to increase concurrently without hindrance. Finally, these bones dovetail at the several sutures, or even unite.

In the *intra-cartilaginous ossification*, ossifying centres also appear, at which the cartilage, more or less metamorphosed, is rendered hard, and in this tissue by subsequent changes, the true osseous tissue, with its cancelli, Haversian canals, laminæ, lacunæ, and canaliculi, is formed. In the case of bones so deposited in a cartilaginous matrix, the outer or *superficial* layers are formed by a sort of intra-membranous process, the pre-existing fibrous structure being derived from the periosteum.

Permanent or perfect bone is therefore neither calcified membrane nor calcified cartilage, but both the membrane and the cartilage act as a nidus, which temporarily gives form and support to the part, and in which the true bone is ultimately developed. As ossification spreads from its centres into the primitive membranes or cartilages, these latter continue to grow until the limits of size are reached.

In most of the short bones, as those of the tarsus and carpus, a single ossific centre exists. In the case of the long bones, as the femur and humerus, tibia and fibula, radius and ulna, clavicle and ribs, and even the metatarsal and metacarpal bones, and the phalanges of the toes and fingers, there is always one ossific centre for the shaft, which, commencing in the middle, spreads towards both ends; and thus the bone grows in length. Besides this, at least one, in most bones two separate centres are formed, one for each end, which, by remaining un-united to the shaft till the bone has attained its full size, facilitate the lengthening of the shaft, and the due expansion of its two ends. The unossified part of the cartilage at each end constitutes the permanent cartilage of the joints. Moreover, the strongly-marked processes for muscular attachment, such as the trochanters of the femur, are formed from separate ossific centres. The medullary cavity, which has no existence in the bones of fishes, batrachians, and reptiles, and contains air in birds, and which is only a larger and elongated cancellus, is hollowed out by absorption as the bone grows; lastly, the bone is increased in thickness by layers deposited from the periosteum. In the irregular bones,—especially such as surround foramina or cavities, as the vertebræ, the occipital and sphenoidal bones, and the hip-bones,—there are many primitive ossific centres, which afterwards unite. The acetabulum is formed by the union of the ilium, ischium, and pubes, which for a long time are separate bones.

The bones begin to ossify at very different times. The clavicle is the earliest, and some of the tarsal, and all the carpal bones, are late, being cartilaginous at birth. The perfect union of the several ossific centres of the long bones occurs only after the full stature is attained.

The Teeth.

Figure 28.

Fig. 28 is a small portion of an incisor *tooth*, to show the microscopic structure of the yellowish *dentine* and the white *enamel.*

The *dentine*, *tooth-substance*, or *bone of the teeth*, consists of a hard material, containing multitudes of minute tubules, making the tooth permeable from within, and from without (in case of exposure of the dentine), and doubtless serving in the nutrition of its substance. These tubules commence at the pulp-cavity, having in the recent state very fine prolongations of the pulp passing into them as they radiate towards the surface of the tooth. In this course they are parallel and wavy; they often divide and subdivide, and so become finer; and their branches anastomose or are lost in the hard *intertubular* substance. This, like the hard substance of bone, is shown, on being softened in dilute acid, to be built up of laminæ and fibres. The dentine is, indeed, similar to, though not identical with, bone; the pulp cavity reminds us of an Haversian canal; the dental tubuli resemble the canaliculi; and, in the teeth of certain animals—as of the horse—lacunæ are met with. Moreover, the tubuli of the dentine anastomose with the canaliculi and lacunæ of the thin layer of true bone, or crusta petrosa, mentioned at p. 88, which is always found on the fangs of the teeth. The dentine, however, contains 72 per cent. of earthy matter, instead of 66, the proportion found in bone.

The *enamel*, or very hard *white* covering of the teeth, consists of microscopic *calcified* *fibres*, which are elongated, hexagonal, or compressed prisms, closely adherent together, set by their inner and smaller ends into corresponding depressions on the surface of the dentine, to which they are fixed, and forming by their outer and larger ends a tesselated surface, which is covered in by a thin structureless calcified layer, called the *cuticle* of the enamel. The enamel-fibres are marked by fine cross striæ. When acted on by an acid, the earthy part is dissolved, and only a trace of animal matter, 2 or 3 per cent., remains.

The dentine and enamel are formed by the metamorphosis and calcification of the microscopic elements or nucleated cells of the tooth-pulp, and of the enamel organ of the sac in which the tooth is formed beneath the gum.

The Voluntary and the Involuntary Muscular Tissue.

Figures 29 to 37.

Fig. 29.—A short piece of a muscular fasciculus of voluntary muscle, magnified 18 diameters. Its actual width would be about $\frac{1}{6}$th of an inch. It consists of many smaller parallel bundles, or *ultimate fasciculi.*

Fig. 30.—A small portion of one of the smallest fasciculi, much more highly magnified, showing that it is composed of still finer parallel parts, named *muscular fibres,* which again, as indicated at one point, are themselves made up of still finer parallel parts named *fibrillæ.*

Fig. 31.—Portions of two of the voluntary muscular fibres, side by side, of which one has its soft substance torn and retracted, so as to exhibit its transparent tube or sheath, called the *sarcolemma,* which invests and insulates each fibre.

Fig. 32.—A planned view of a portion of a single fibre, still more highly magnified, showing its component fibrillæ, resulting, as it were, from a longitudinal severance of the substance of the fibre. It also exhibits a mode sometimes observed of splitting transversely into discs.

A *voluntary muscle* then consists, according to its size, of a few or of multitudes of ultimate parallel bundles, or *fasciculi,* fig. 29, held together by areolar tissue, blood-vessels, and nerves,—the whole being surrounded by a sheath, with which the areolar tissue between the fasciculi is connected (see diagram No. 2, p. 20). These fasciculi are composed of aggregations of *muscular fibres,* figs. 30, 31, 32, which are soft, solid, compressible, prismatic fibres, arranged side by side, measuring on an average about $\frac{1}{400}$th of an inch in width, and beautifully marked with fine cross lines, *striæ* or stripes : hence they are called *striped muscular fibres.* These fibres run the whole length of a fasciculus, and are held together by a very fine areolar tissue, and also by the capillary vessels, which lie between them in form of an elongated network, fig. 59. The striped muscular fibres are found, on farther examination, to be each enclosed in a transparent, structureless, flexible and elastic tubular membrane, called the *sarcolemma,* fig. 31, which thus surrounds and insulates every fibre. Within the sarcolemma are sometimes found the remains of the nuclei concerned in the original formation of the fibre (see fig. 14, and p. 231). The soft enclosed substance of the fibres is yellowish and pellucid, and on being frayed out with needles under the microscope, as in fig. 30, is separated longitudinally into several hundreds of fine threads or *fibrillæ*, about $\frac{1}{10000}$th of an inch in width, which, as shown in fig. 32, appear to be composed of rows of little ultimate elementary particles, called *sarcous elements*. These particles, which have been described as being globular, and the fibrils beaded, appear rather to be fitted together by square ends, and so to cohere in longitudinal series to form the numerous fibrillæ. Moreover, being of uniform size, and being arranged most accurately side by side in all the fibrillæ of the fibre, they produce the characteristic appearance of the cross striæ or stripes; and occasionally the substance of the fibre splits in the direction of these striæ, that is, in the intervals between corresponding rows of sarcous elements, into transverse discs, fig. 32. These sarcous elements contain principally a peculiar animal substance, called *muscular fibrin*, or *syntonin*, from συντεινω, *synteino*, to contract. They are the seat of the vital contractility of the muscular fibre.

Fig. 33 illustrates the changes which a voluntary muscular fibre undergoes during its contraction.

In this contraction, which is an active state, the fibre, as shown in the figure, becomes shorter and thicker; but it undergoes no appreciable change in bulk. The transverse stripes approach more closely together; and hence it is inferred that the little square-ended sarcous elements composing the fibrillæ themselves change their form, become shorter and wider, and so produce the change in form of the entire fibre, including the approximation of its transverse striæ. When the fibre relaxes, or assumes a passive state, the sarcous elements resume their normal length and width, the fibre its previous condition, and the cross lines their ordinary distance from one another. The act of contraction is not exactly simultaneous along the entire length and breadth of a fibre, but, beginning at one point, quickly invades the whole; and successive contractions follow one another in an undulatory manner. When the fibre finally relaxes, it is often thrown into a zigzag or waved line, until its ends are drawn apart by some counteracting force, or until it again contracts.

All the fibres in any given fasciculus or muscle do not act together, but in rapid succession one after another, so that each has a brief period of rest, whilst the muscle, as a whole, continues its action. The total effect is to shorten the muscle by about one-third, and increase its width proportionably. It has already been stated that there is no appreciable alteration in the bulk or capacity of a muscle, when it contracts; but though there cannot, therefore, be any condensation of the sarcous substance, it is remarkable that there is a manifest hardening or rigidity. This is not wholly due to the tightening of the muscle between its two fixed points, for it occurs in detached fragments of the tissue also. It may in part depend on a certain resistance offered by the elastic tubular sarcolemma surrounding each fibre to the lateral enlargement of its sarcous substance. The elasticity of the sarcolemma may further assist in restoring the swollen fibre to its previous narrower condition as it relaxes; at any rate, the sarcolemma must rapidly accommodate itself to the changing form of the sarcous substance which it invests.

Fig. 34.—A voluntary muscular fibre ending directly in a bundle of the common fibrous or tendinous tissue.

Fig. 35.—Voluntary muscular fibres ending obliquely on the side of a tendon.

The two preceding figures illustrate the mode of attachment of the voluntary muscular fibres to the tendinous structures, by which means, as explained in diagram No. 2, at p. 20, this contractile tissue, acting on the bones or other parts, is utilized in the body. In the direct mode of attachment, fig. 34, the fibrillæ gathered into bundles, surrounded with fine connective tissue, become continuous with filaments of the fibrous tissue; in the oblique mode, when narrowly examined, a similar transition is observed, and as the central fibrillæ of each muscular fibre are the last to change into fibrous tissue, the entire muscular fibres appear to end in conical points inserted into depressions on the surface of the tendon.

In the muscles, the individual fibres run, without dividing or uniting, from one end to the other of the fasciculus to which they belong. In the tongue, lips, and face, where the muscular fibres end in the mucous membrane or the skin, they first divide into fine branches, which ultimately become continuous with filaments of connective tissue.

The blood-vessels of the voluntary muscles are very numerous. Their capillaries, fig. 59, run between the fibres, forming elongated muscles between them, but never penetrating the sarcolemma. Lymphatics exist in the areolar tissue between the muscular fasciculi. The nerves of the muscles are large: they branch out, from little plexuses, and end chiefly in arched loops, formed of one or more nerve-fibres, which cross amongst the muscular fibres (see diagram No. 7, fig. 10, and p. 112). Some of the nerve-fibres appear, however, to end or become lost amongst the muscular fibres, but there is no evidence of their penetrating the sarcolemma; so that the influence of their stimulus on the muscular fibres is apparently one of contact only. The nerves of muscles are of course chiefly efferent or *motor;* but a certain number of afferent or *sensory* fibres must exist intermixed with them, by which a knowledge of the state of the muscle, or its degree of contraction, is conveyed to the sensorium, constituting what is called the *muscular sense.*

Fig. 36.—Portions of four involuntary muscular fibres from the bladder,—the one to the right acted on by diluted acetic acid.

The *involuntary muscular tissue* is found in the substance of the heart, in the muscular coats of the alimentary canal, the gall-bladder, and the ducts and excretory apparatus of glands generally; in the coats of the spleen; in the walls of the arteries, veins, and larger lymphatics; in those of the trachea, bronchi, and bronchial tubes; in the skin, and in the iris and ciliary muscle.

Speaking generally, the involuntary muscular tissue consists of fibres, which are less highly organized than those of the voluntary kind. In the heart, the fibres so far resemble these latter, as to be reddish-coloured and marked by transverse stripes; but they differ in frequently dividing and uniting together again, and also, it is said, in having no sarcolemma.

Everywhere the involuntary muscular fibres are pale, softly granular, and smooth, having no transverse striæ; hence they are called *plain, nonstriated,* or *unstriped muscular fibres.* They vary in size from $\frac{1}{7000}$th to $\frac{1}{3500}$th of an inch in width, are roundish or somewhat compressed, have no sarcolemma, consist of sarcous elements, scattered or else arranged in longitudinal rows, and contain peculiar oblong nuclei, which are rendered more evident on the application of diluted acetic acid. Stronger acids, such as the nitric and chromic acids, have the effect of breaking up the involuntary muscular fibres into fusiform portions, each inclosing one of the oblong nuclei just spoken of, and called *contractile fibre-cells.* These cells appear to be the elementary parts or cells of the involuntary muscular fibre, though, according to one view, they are the result of artificial severance; but in the skin, and in the coats of the *spleen*, single or naturally isolated contractile fibre-cells are found.

> Fig. 37 represents two such nucleated contractile fibre-cells from the gullet of the pig; one very large fibre-cell from the human intestine; and also one from the elastic and contractile coat of the spleen of a dog: the two latter are not treated with nitric acid.

The involuntary muscular fibres are generally grouped together into larger or smaller fasciculi, which interlace with each other to form membranous structures, such as the muscular coats of the intestines and bladder; or a thicker mass, as in the heart. Their ends are inserted or merge into little bundles of the white fibrous tissue of the parts to which they belong.

The vital contractility of the muscular substance, or *vis musculosa*, *muscular power*, is inherent in it, and may be excited by various mechanical, chemical, and electrical stimuli; but it is usually excited and controlled by the motor influence of the nervous system, manifesting itself then either in reflex, sensori-motor, or voluntary acts (see diagram No. 7). The involuntary muscular structures are not of course subject to the will, but are governed reflexly through the spinal and sympathetic systems.

In producing the various movements of the body, the muscles not only shorten and widen, but they give out a vibrating sound, named the *muscular sound*, which is easily heard on placing the ear upon a muscle in action, and appears to be due to the friction of the fibres on one another. Chemical changes, involving a waste of the muscular substance, also take place; and a rise of temperature, dependent on oxidation, and possibly on friction, ensues. Lastly, electrical currents are produced. Even after the death of an animal, the smallest portion of muscle exhibits for a time a particular electric or polar condition of its particles.

The contraction of involuntary muscles is usually slow and progressive, as in the large arteries and in the intestine; but it may be rapid as in the case of the iris, or quick and rhythmic as in the heart. Voluntary muscles act either slowly or quickly; their reflex movements are generally rapid. The longer the fibres of any muscle, the greater is the velocity of its action; the more numerous its fibres, the greater its power.

A certain temperature and state of nutrition are necessary to the action of the muscles; the power of a limb being lessened or destroyed by chilliness, or deficiency or deterioration of the blood. A renewal of the nutritive supply, a restored circulation, and soon after death even, the injection of warm blood into the vessels, will revive the lost contractile property. Over-exercise, and undue stimulation, by lightning, by electrical shocks, by violent emotional stimuli, or from some deranged state of the nervous system, as in hysteria or epilepsy, exhaust the muscular contractility. But moderate exercise and stimulation, followed by sufficient rest, increase the size, the activity, and the power of the muscles. Disuse is followed by weakness and wasting. That continuous state of gentle contraction called "*tone*," or "*tonicity*," has been alluded to at p. 137.

The contractility of muscle lasts only a few hours after death in warm-blooded animals, but for some days in cold-blooded air-breathing creatures, such as the turtle and frog.

Some time after death the muscles become rigid, and thus give a peculiar stiffness to the corpse. This *rigidity*, or *rigor mortis*, is a positive sign of death. It seems as it were dependent on an expiring effort at contraction; but its precise cause is not known, though it undoubtedly is seated in the muscular tissue.

Besides 75 per cent. of water, and 15 per cent. of the peculiar fibrine called *syntonin*, muscle contains 4 per cent. of fatty matters, and a residue of albumen, certain organic bases, named creatin and creatinin, organic acids, viz., lactic, inosinic, acetic, butyric, and formic acids; a peculiar kind of sugar called inosite, and alkaline and earthy phosphates. The most abundant of these subordinate chemical substances is the *creatin*, which seems to be the first result of the decomposition of the syntonin, and to be itself afterwards changed into creatinin, which with other products are capable of being absorbed by the veins, and are then removed from the circulation by the kidneys, skin, and other glandular organs, or are converted into carbonic acid, and eliminated by the lungs.

The Nervous Tissue.

Figures 38 to 48.

The three essential microscopic constituents found in the several parts of the nervous system are the *white* or *tubular* fibres, the *grey* or *gelatinous* fibres, and the *ganglionic nucleated cells*. The modes in which these are intermingled in the cerebro-spinal axis, in the cranial and spinal nerves, and in the sympathetic ganglia and nerves, have been fully described under diagram No. 7.

Fig. 38.—Plan of a portion of a spinal nerve, giving off two branches, and composed of an assemblage of parallel cords, called *funiculi*, of which one is seen projecting from the rest. Enlarged about 10 diameters. Each funiculis is composed of many finer parallel elements, the white or tubular *fibres*.

Fig. 39.—*White tubular nerve-fibres* from different parts of the nervous system, and in different states. Magnified very highly, but equally. *a*, fibres of different diameters, with clear contents and characteristic double outline, from the trunks of nerves,—two of them, finer than the rest, have lost their double outline; *b*, fibres, which, from pressure or other cause, have assumed a beaded or varicose character, after removal from the body; *c*, fibres, the contents of which have become altered and grumous from the action of water on them; *d*, fibres from the brain,—four exceedingly fine, one being varicose, and the rest larger, and exhibiting the characteristic structure of all the white tubular fibres, viz., a *central band* seen in one case projecting at the upper end, named the *axis*, *axis cylinder*, or *primitive band*, an outer transparent homogeneous membranous *tube*, and lastly an intermediate white or *medullary substance*.

Fig. 40.—Origin of a spinal nerve (see p. 128), by *two* bundles of funiculi, called *roots*,—one posterior or sensory, which has a knot of mixed grey and white substance named a *ganglion* upon it, the other anterior or motor, which passes over the

ganglion and joins the posterior root beyond it, to form the mixed motor and sensory trunk of the nerve. Enlarged 8 times.

Fig, 41.—Enlarged plan of a section of a spinal ganglion, showing the sensitive root passing through it, and the motor root over it. The circular outlines represent the ganglionic cells of the grey matter, amongst which some of the white fibres of the posterior root merely pass, whilst others appear to commence in the ganglion itself.

Fig. 42.—The granular, coloured, and nucleated cells, called *ganglionic cells*, *nerve-cells*, *nerve-vesicles*, or *ganglionic corpuscles*, from the grey substance of a spinal ganglion. These and the succeeding illustrations, down to fig. 48, are very highly magnified. The nerve-cells vary in size and form, being either spherical, pyriform, or developed into fine processes, which are found to connect efferent cells together, or to become continuous with certain of the white tubular fibres.

Fig. 43.—A small portion of a *spinal ganglion*, much more highly magnified than fig. 41. Besides showing the rounded ganglionic cells, covered with granular corpuscles, and three white fibres passing between them, it exhibits a number of the *grey gelatinous fibres*, which are soft, non-tubular, and have numerous dark nuclei in their course.

Fig. 44.—Three ganglionic cells from a *sympathetic ganglion*, one having a short broken process leading from it.

Fig. 45.—Three nerve-cells from the grey substance of the *spinal cord*, having a radiate or stellate form, owing to the number of processes given off from them. One has a double nucleus, as if it were about to divide.

Fig. 46.—Two nerve-cells of very large size, from the grey substance of the *medulla oblongata.*

Fig. 47.—Three nerve-cells from the grey substance of the convolutions of the cerebrum; also two small nucleus-like bodies found in great numbers in that situation, and also in the cerebellum.

Fig. 48.—A single large nerve-cell from the outer grey layer of the cerebellum. One of its processes is seen to be subdivided into branches.

The white fibres of the nerves and nervous centres, as shown in fig. 39, *a*, are minute membranous tubes, varying in size from $\frac{1}{12000}$th to $\frac{1}{1500}$th of an inch in width, containing a central axis or band, surrounded by medullary substance. This latter when freshly examined is transparent, soft, and fluid, but on getting cold, or on being acted on by water, becomes as it were congealed and grumous, gathers into semi-fluid drops, or escapes at the end of its containing tube, *a*, *c*, *d*: being soluble in ether, it is decidedly fatty. The central axis or primitive band is apparently of fundamental importance; for in certain places, as will presently be mentioned, it is the only part of the nerve-fibre left. It is firm and strong, and is often left projecting from a torn fibre as at *d*. It is not fatty, but consists of a peculiar protëin substance, differing, however, from the fibrine of the blood and muscle. The white fibres are finest in the brain, larger, but still fine, in the sympathetic system, and largest in the cerebro-spinal nerves, especially in the motor nerves; but otherwise no difference is perceptible between motor and sensory fibres.

In the brain and spinal cord, the white fibres, held together by a soft granular matrix, are disposed in bundles or layers, serving either as the deep origins of roots of the nerves, or connecting together the various masses of grey substance, in which some of them pass between the ganglionic cells, whilst others, losing their tubular membrane and medullary substance, and reduced to the axis or primitive band only, become continuous with the curious processes given off by many of those cells. In the ganglia they are similarly connected.

On emerging from the brain or cord, the white fibres are gathered into cords called *funiculi* (see fig. 40), each of which is surrounded by a fine sheath, called the *neurilemma.* The funiculi are gathered into bundles or *fasciculi*; and these again, held together by areolar or fibrous sheaths, form the *nerves.* The nerves as elsewhere mentioned (diagram No. 7, pp. 128-9), divide and anastomose, so as to form plexuses, and ultimately ramify in the muscular and sensitive tissues of the body. In this course the fasciculi and funiculi of different nerves frequently interlace, and even the ultimate nerve-fibres of neighbouring funiculi may be interchanged; but so, as far as is known, these fibres themselves never divide or join together, but remain continuous and independent from their origin to near their termination, where sometimes, losing their outer tube, and becoming reduced to their central axis only, they may divide and subdivide just before they are finally lost in the tissue to which they are distributed. Sometimes they end by anastomosing so as to form loops. See the account of the various organs and tissues.

The *ganglionic cells*, already sufficiently described with figs. 42 to 48, are vesicular, oval, pyriform, caudate, or stellate nucleated cells, which either lie amongst the nerve-fibres, or are connected with each other, or with the axial band of certain of the white fibres, by their curious processes.

The *grey* or *gelatinous* nerve-fibres, proper to the sympathetic system, but imparted in small numbers, in exchange for a few white nerve-fibres, to the spinal and cranial nerves, have a soft granular appearance, have no containing tube, and an abundance of contained nuclei. They thus differ wholly from the perfect tubular or white-nerve fibres, but somewhat resemble the earlier stages of development of these latter. The perfect fibres of the olfactory nerve in the nose resemble very closely the grey sympathetic fibres.

The supposed functions of the vesicular and fibrous elements of the nervous tissue have been fully discussed under diagram No. 7. They depend on a peculiar vital property, designated the *vis nervosa*, the nature of which, however it may resemble electricity, or be correlated to physical forces, is yet unknown to us.

The grey vesicular matter of the brain contains 85 per cent. of water, 7 of a protein substance, 5 of fat, and a residue of salts, amongst which phosphates abound. The white or fibrous matter consists of 73 per cent. of water, 10 of a protein substance, 15 of fat, and a similar saline residue to the grey matter. The fat appears, in part at least, to be peculiar, consisting of a fatty acid called *cerebric*, and of oleic acid combined in some way with phosphorus. The brain also contains some cholesterine.

The Vascular Tissue.

Figures 49 to 64.

Under this head is described the structure of the *walls* of the *arteries*, *veins*, and *capillaries*. Some additional particulars are also given of the blood and its corpuscles, and of the various arrangements of the capillary vessels. The structure of the lymphatic vessels and the microscopic constituents of the lymph and chyle are considered under diagram No. 5.

The tissues previously described in this diagram, namely, the areolar, fibrous, cartilaginous, osseous, muscular, and nervous tissue, are simple or elementary; but the vascular tissue, and also the serous, synovial, and mucous membranes, and the glandular tissues, are composite, or composed of mixtures of the more elementary tissues, as will be immediately seen.

Fig. 49.—Portion of an *artery* cut open, and its walls separated at the upper end into *three* tissues or *coats*.

The *outer* coat of the arteries, or *areolar* and *elastic* coat, for it is composed of those two tissues intermixed, is strong and tough, of a whitish colour, and connected loosely with the areolar sheath, which surrounds all arteries but those in the cranium and the spinal canal. This coat is absolutely thickest and most elastic in the larger arteries; but it is relatively thicker, though less elastic, in the smaller ones. The *middle* or *muscular coat*, of an opaque yellowish colour, on which the thickness of the walls chiefly depends, is composed of plain or unstriped muscular fibres, arranged in a circular manner around the vessel, overlapping one another, and supported by a web of fine areolar and elastic tissue. This, the most characteristic of the arterial coats, is the thickest of the three, but is soft and tender, and is easily torn away in circular layers or strips, as many as forty having been so made in the aorta. It is much mixed with elastic tissue in the larger arteries, and more purely muscular in the smallest ones. The *inner*, *elastic* and *epithelial* coat consists of a web of fine elastic fibres, of a perforated or fenestrated elastic membrane, such as is represented in figs. 19 and 20, and of a lining stratum of fusiform scaly epithelium cells (see fig. 73). This is the thinnest coat, and is very brittle.

When an artery is tied tightly with a fine cord, the inner, brittle, and the middle, soft, coats are cut neatly through in a circular direction, but the outer tough coat is merely closely ligatured, and if the cord be untied, is seen to remain unsevered. When an artery is tied during life, the divided ends of the middle coat (which is highly vascular) retract slightly, and exude a living blastema, in contact with which the blood in the vessel coagulates for a short distance, so as to form a plug; the blastema becomes organized, and then, the vessel being effectually closed, the part of the outer coat which had remained entire but strangled in the ligature becomes detached by an ulcerative process, and so the thread is safely cast off. An artery tied at the end of an amputated limb is closed in the same way. When an artery is torn across by stretching or twisting, its muscular coat contracts, and the torn vessel retracts within its sheath, and thus the formation of a clot, and the subsequent adhesion of the surfaces of the vessel, are favoured. These are good examples of provision against such accidents to the living body as are inevitable from the very nature of things. The arteries are also liable to a disease called *aneurism*, which is a dilatation of the vessel, and which may likewise be cured by ligature, or by prolonged compression.

The walls of the arteries, except the epithelial layer, are themselves supplied with blood-vessels, appropriately named *vasa vasorum*, the *vessels of the vessels*, and derived from fine offsets from other vessels ramifying in the sheath. The arteries also receive many nerves belonging to the sympathetic system, containing, in the case of the larger vessels, a very few white fibres from the cerebro-spinal system. The nerves of the arteries do not confer sensibility on them, but are concerned in the governance of the slow contractility possessed by their muscular coat (see pp. 116 and 138). The effects of this contractility may be seen, under the microscope, in the arteries of the web of the frog's foot, the wing of the bat, and the mesentery of the mouse: it is most marked in the smaller vessels. Acting further than the mere elasticity of the other tunics, it adjusts the calibre of the vessels to the quantity of blood in the system at any given time, and doubtless regulates the share received by particular organs at particular times. By offering less or more resistance to the blood-current, it counteracts and renders equable the impulses of the heart. It is the cause of what is called the tone or tonicity of the vessels; and, when relaxed, leads to congestions, as seen in blushing, and in certain stages of inflammation.

Fig. 50.—Enlarged view of a portion of a middle-sized *vein*, opened to display its *valves*, and dissected to show its *three coats*.

The walls of the veins, thinner and more transparent than those of the arteries, permit, even during life, the deep-red hue of the venous blood to be distinguished through them, and then have a bluish-purple aspect; whilst the arteries, being opaque, have their own yellowish-white colour. The *outer*, *areolar* coat has, in the large veins of the abdomen, a few unstriped muscular fibres in it. The *middle* coat, chiefly areolar and elastic, also possesses circular plain *muscular* fibres. The *inner*, or *epithelial* coat, less brittle than that of the arteries, has no fenestrated membrane, but is lined with a layer of thin, flat, oval, or fusiform epithelial cells (fig. 72). In the cranium, and in the interior of the bones, the veins have no muscular fibres, and, indeed, no proper middle coat. In the lower limbs, especially in the superficial veins, the coats are all very thick. The veins have their vasa vasorum, and the larger veins are provided with a few nerves: they possess but little vital contractility. The great veins close to the heart, however, contract quickly and rhythmically, like the auricles into which they open, and are there covered with striped muscular fibres. The veins in the bat's wing are found to contract rhythmically about ten times in a minute.

The *valves* of the veins, already noticed at p. 65, are composed of a fold of the inner coat, strengthened by included areolar and fibrous tissue.

Fig. 51.—Under surface of the web of the frog's hind foot, the natural size; and also enlarged, to show the branchings of its small arteries and veins.

Fig. 52.—Portion of the web between two of the toes, further enlarged, to exhibit the network formed by the ramifications of the terminal blood-vessels or *capillaries*, placed intermediately between the arteries and the veins.

Fig. 53.—Smaller portion of the marginal part of the web, still further magnified, and showing, to the left hand, a minute artery, and to the right hand a minute vein, the two being joined by a network of intermediate vessels or capillaries. When thus examined during life, the blood-current is seen moving, as indicated by the arrows from trunk to branches along the artery, and from branches to trunk along the vein. The oval bodies within the vessels are the red corpuscles of the frog's blood. The black specks between the vessels are the stellate pigment-cells of the frog's skin.

Fig. 54.—Three red blood-corpuscles from the frog,—one turned on its edge. Magnified 2,800 diameters.

Fig. 55.—Two red blood-corpuscles of a fish, viz. the *monk-fish*, Squalus squatina,—one seen edgewise. Magnified 3,300 diameters.

Fig. 56.—Two red blood-corpuscles from the *common fowl*. Magnified 3,300 diameters.

Fig. 57.—Three red blood-corpuscles from the *goat*,—one seen edgewise; also a minute white corpuscle. Magnified 3,300 diameters.

Fig. 58.—Portion of a *human* capillary vessel, showing its distinct homogeneous membranous walls, with nuclei in them. Seven red blood-corpuscles are contained within the capillary vessel,—two seen edgewise, one seeming as if bent or curved around one of the three white blood-corpuscles, also represented here. Magnified, like figs. 55, 56, 57, about 3,300 diameters.

Fig. 59, and the succeeding figures to 64, not so highly magnified, show the forms assumed by the capillaries in different tissues. This figure represents the capillaries of voluntary muscle.

Fig. 60.—Capillaries of the great intestine of the frog.

Fig. 61.—Capillaries of the papillæ of the human *skin*.

Fig. 62.—Capillaries of the *villi* of the human intestine.

Fig. 63.—Capillaries of the walls of the *air-cells* of the human lung.

Fig. 64.—Capillaries surrounding the terminal vesicles of the *parotid gland*.

The capillaries are usually arranged in form of a *network*, sometimes with elongated meshes, as in muscle, fig. 59, tendinous tissue, and the nerves, but generally with polygonal meshes, either open, as in a smooth mucous membrane, fig. 60; or closer, as in the intestinal villi, fig, 62, or in the lobules of glands, fig. 64; or, closest of all, in the lungs, fig. 63, where the interspaces of the meshes are not wider than the vessels themselves. More rarely, as in the finest papillæ of the tongue and skin, fig. 61, the capillaries form *loops*, being drawn out, as it were, with the growth of the papillæ.

The capillaries of the marrow of bones are the largest in the body, measuring $\frac{1}{1200}$th of an inch; capillaries of medium size are about $\frac{1}{2500}$th; those of the lungs are about $\frac{1}{3000}$th; and in the brain they have been found to measure, after death, when injected artificially, only $\frac{1}{4500}$th; but in life they probably admit the red particles of the blood, which average $\frac{1}{3500}$th of an inch in diameter.

The walls of the finest capillaries consist of homogeneous membrane, the nuclei in them being the remains of those of the coalesced cells (fig. 15) of which those vessels are formed. Near the ultimate arteries and finest veins, the capillaries gradually acquire a few circular muscular fibres, then some longitudinal elastic fibres, and then an outer areolar, and an inner epithelial coat. The capillaries are nourished directly from the transuding fluid parts of the blood. They are not sensitive; and the result of experiments still leaves it doubtful whether the variations in calibre to which they are liable are due to vital contractility or to mere elasticity of their walls.

The varieties in the size and form of the red corpuscles of the different classes of mammalia are illustrated in figs. 54 to 58. They are invariably flattened or discoid, small, and nearly circular, or of moderate size and oval in fishes, fig. 55; they are much larger and oval in the frog, and in the batrachia, and in reptiles generally,—being the largest of all, $\frac{1}{400}$th of an inch long, in the proteus. They are oval and of medium size in birds, fig. 56. In the mammalia generally they are circular, but they are elliptical in the camel tribe. To some extent, their size has a relation to that of the animal, but not entirely or universally so. They are very small in the goat, fig. 57, about $\frac{1}{6400}$th of an inch; but are smallest in the Napu musk-deer, being only about $\frac{1}{12000}$th of an inch in diameter.

The red corpuscles, in the fish, batrachian, reptile, and bird,—that is in the oviparous vertebrata, are distinctly nucleated cells, consisting of a thin cell-wall or envelope, enclosing coloured contents, and a central pale solid oval nucleus, which projects a little on each surface of the disc-like corpuscle (see figs. 54 to 56). In some of the mammalia, and probably in the earliest stages of development of all,—of man included,—the blood corpuscles also possess a distinct nucleus; but, when fully formed, the nucleus disappears and a sort of cup-shaped depression exists on each surface of the corpuscle, with a circular rim round it (see fig. 58). In the living vessels, the red corpuscles flow freely along the centre of the current, and are so soft, flexible, and elastic, that they bend around any corner or obstacle, such as the angles of the vessels, or the white corpuscles, as seen in fig. 58; and then, after passing them, resume their shape.

The white corpuscles, fewer in number than the red ones (see p. 68), and resembling in all respects the corpuscles of the lymph and chyle, from which they seem to be derived (see p. 79), have a peculiar tendency to adhere to the inside of the capillary vessels (see fig. 58), along which they move slowly in proportion to the swifter red corpuscles.

In the oviparous vertebrata, it is believed that the white corpuscles are directly changed into coloured ones; but in the mammalia, including man, it is thought that the nucleus only of the white blood-cell, escaping from its envelope, becomes the red corpuscle.

Besides these two kinds of characteristic corpuscles, the blood contains molecules of fat, shreds of various forms, and other irregular-shaped bodies, which seem to be due to various conditions of aggregation and de-gradation of the white and red corpuscles.

Considered as regards its composition, 1,000 parts by weight of blood consist of about 500 parts of red and white corpuscles, and 500 parts of fluid blastema or liquor sanguinis. The 500 parts of corpuscles contain 345 parts of water, and 155 parts of dry solid matter, whilst the liquor sanguinis contains 450 parts of water, and only 50 parts of solids; hence the total quantity of water in the blood is 795 parts to 205 of solid matter. The 155 parts of solid materials of the corpuscles consist, first, of 140 parts of albuminous substance, called *globulin*, of which the substance of the corpuscles is chiefly composed, together with a peculiar matter which constitutes their envelopes; secondly, of about 85 parts of a deep-red organic substance, called *hæmatin*, which is the colouring matter of the red corpuscles, and is remarkable for containing iron, not, it would seem, as a constituent essential to its colour, for the iron may be removed without destroying this, but in some intimate state of admixture,—the total quantity of iron so combined being about ¾ of a grain in 1,000 grains of blood; thirdly, of about 1 part of fatty matter, and 1·5 of extractive matters; and, lastly, of 4 parts of saline substances, consisting chiefly of the chloride of potassium and phosphate of potash. The 50 parts of solid materials of the liquor sanguinis consist, first, of a fraction more than two parts of a very characteristic protein constituent, in a state of solution, named *blood-fibrin*, which is the coagulating element in the blood; secondly, of 39·5 of albumen of the serum; thirdly, of nearly 1 part of fatty matter, and nearly 2 of extractive matters; and, lastly, of about 4·5 parts of saline substances, of which the chief are chloride of sodium and phosphate of soda. There are also in the blood, as a whole, carbonates and sulphates of potash and soda, and carbonates, sulphates, and phosphates of lime and magnesia. The extractive matters consist of creatin and creatinin, substances found in the flesh, and also, the last especially, in minute quantities, in the renal excretion. There are likewise traces of sugar, or a sugar-forming substance, especially found in the blood of the hepatic veins. Urea, and even urate of soda, are also found in the blood; and, lastly, the blood contains colouring matters like those of the bile, and odoriferous substances, which cause the peculiar smell of different animals. Finally, it holds in solution, or in some slight mode of combination, from 7 to 10 per cent. of carbonic acid, oxygen, and nitrogen gases, in the relative proportions of 7, 2, and 1.

Just as when viewed structurally, the blood is a fluid blastema, containing organized cells, or products of cells, so, viewed chemically, it is a sort of liquid flesh, containing globulin, albumen, and fibrin. The chief part of its solid constituents being found in the red corpuscles, these are supposed to elaborate and furnish by dissolution into the liquor sanguinis the materials used for the nutrition of the textures, and for the processes of nutritive secretion to be presently mentioned. The fatty matter, and the alkaline and earthy salts, are the same as or similar to those found in the various soft and hard tissues. The creatin, creatinin, urea, sugar, and colouring and odorous matters, represent some of the products of decomposition of the tissues, especially of the muscles and nervous substance,—or they are the products of certain secretory processes,—in either case, being on their way to the several excretory organs, they are to be cast off. The gases are both the agents and the results of the respiratory changes, indicative of a progressive process of oxidation of the used-up materials and other substances, such as fat, sugar, and perhaps lactic acid, which supply fuel for vital combustion and the evolution of animal heat. The difference observable in the colour of arterial and venous blood, due to the respiratory process, is attributable to changes in the action of the red corpuscles on solar light, owing, it is thought, to modifications in the form or molecular arrangement. This fact has led to the supposition that the red corpuscles are the vehicles or carriers of the oxygen and carbonic acid interchanged during respiration (see p. 49).

When a drop of freshly-drawn blood is placed between glass and examined under the microscope, the red corpuscles are seen, after a short time, to run together into little rows, like rolls of coin (see diagram No. 4, fig. 12); and furthermore the fibrin, which during the living state of the blood is in complete solution, speedily concretes in little particles, which cohere into exceedingly fine homogeneous fibres, which form an intricate maze of meshes, in which the red and white corpuscles are entangled. On a larger scale, the same changes take place in a pint as in a drop of blood, whenever this fluid is drawn from the vessels, or removed from the circulation by an internal rupture and pouring-out of blood into the tissues, as occurs in bruises; the fibrin solidifies and entangles the cohering corpuscles into a dark red jelly-like mass, which is called the *clot* or *coagulum* of the blood, whilst the residual nearly colourless fluid part of the liquor sanguinis, now deprived of or separated from its fibrin, is called the *serum* of the blood. This serum is, in fact, the liquor sanguinis, minus its 4 parts in a 100 of blood fibrin. As the clot shrinks, more and more of this serum is forced out from it.

This curious spontaneous separation of the blood into clot and serum is called the *coagulation of the blood.* That its immediate cause is the solidification of the fibrin is shown by the fact that if the blood, when drawn, be immediately beaten with a bundle of fine twigs or wires, the fibrin concretes upon these, and may be then completely removed, the residual fluid, or *defibrinated blood*, being no longer capable of coagulating. Why the fibrin thus solidifies is even yet not thoroughly explained; but the important consequences of this fundamental property of blood are recognized in the living frame in the arrest of hemorrhage, by the temporary closure of the smaller blood-vessels, by the firmer pressure produced by a clot than by a fluid exudation, and by the actual plugging up of the large vessels;—the exuded blood forms a preliminary bond of union between divided parts, and may even become subsequently the nidus of future organization.

But the union and restoration or regeneration of parts is actually performed by the exudation or pouring-out from the liquor sanguinis of a sort of liquid blastema, in which, as it becomes more solid, nuclei or cells arise, and certain changes take place in these, or in the blastema, apparently under their influence, which result in the development of the tissue to be restored. This exudation is called the *plasma*, from πλασσω, plasso, to make.

The tissues which can thus be perfectly regenerated, are the areolar, the fibrous, the osseous, the white or tubular nerve fibres, the epithelial and epidermic tissues, including the nails and hairs, and, lastly, the capillaries and the blood itself. Cartilage and fibro-cartilage, the muscular fibres, the grey nervous substance, the larger blood-vessels, the specially characterized parts of the mucous membranes and the skin, the glandular tissues, and certain portions of the organs of the senses, are not regenerated,—injuries to or losses of those parts being usually repaired by an areolar or fibrous structure.

The Secreting Membranes and Glands.

Figures 65 to 70.

The simplest secreting membranes in the body are those closed sacs called *serous membranes*, such as the pleura (p. 31), the pericardium (p. 31), the peritoneum (p. 33), the arachnoid membrane (p. 124), and the lining membranes of the heart, and of the ventricles of the brain (p. 121). These consist of an interwoven layer of areolar and elastic fibres, in which blood-vessels, lymphatics, and a few nerves are found. On certain parts of this can often be demonstrated a thin covering of a homogeneous or structureless appearance, called a *basement membrane*, on which rests a single layer of scaly *epithelial* cells (see fig. 71), which form the actual surface of the membrane. From this surface a very simple albuminous fluid exudes, formerly compared to the serum of the blood,—whence the name of these membranes,—but in reality it is more like a feeble liquor sanguinis, for it contains a trace of fibrin. In health it only exists in sufficient quantity to moisten the surface of the membrane ; in excess, it constitutes dropsy.

The next more complex secreting membranes are the closed sacs called *synovial membranes*, which line the joints (p. 14), the sheaths of tendons (p. 22), and the bursæ in different situations (p. 19). These differ from the serous membranes, first, in often having an epithelial covering consisting of several layers of cells ; secondly, in often being provided, in the two first-named varieties, with beautiful *projecting* vascular *fringes*, called the *glands of Havers ;* and, thirdly, in secreting a much more viscid albuminous fluid called synovia (p. 14), which contains a few corpuscles exactly like the white corpuscles of the blood. There are, however, some bursæ situated beneath the skin, over prominences of the bones, which are more like largely-developed areolar spaces, for they have no epithelial lining.

But the most complex of all secreting membranes are those known as the *mucous membranes*, which, as the following general description will show, are far more highly organized, more vascular, more nervous, and yield more special and important secretions than the serous and synovial membranes.

The mucous membranes do not form *closed sacs*, but open on the surface of the body, and line the air-passages, the digestive and the urinary canals. The chief of these membranes is the *gastro-pulmonary* mucous membrane, which, commencing at the mouth and nose, extends throughout the pharynx, gullet, stomach, and intestinal canal, is continued along the ducts of every gland in its course, and which also passes along the larynx and air-tubes into the lungs : there are extensions of this membrane into the sinuses connected with the nose, along the Eustachian tube into the drums of the ears, and along the lacrymal passages to the eyelids. The several parts of this extensive membrane, or internal skin, have been already described in diagrams Nos. 3, 6, 7, and 8.

Viewed generally, the mucous membranes consist of an areolar and elastic layer, which is supplied abundantly with blood-vessels, lymphatics, and, especially near the outlets of the body, with nerves,—in some places, too, with a few unstriped muscular fibres ; this layer is smoothed over with a thin homogeneous *basement membrane*, not demonstrable in every situation ; and this again is covered in with an *epithelial layer*, varying very much in the number and character of its cells in different parts. In some situations, as in the nasal sinuses, the entire membrane is thin and *smooth ;* in others, as in the mouth, it is thicker, and provided with vascular and nervous eminences, called *papillæ ;* in others, as in the small intestines, it is softer, and has vascular projections called *villi ;* and at certain parts, as in the small intestines, it is thrown into large folds named *valves*. Again, the mucous membranes are in some places inflected or *recessed* into shorter or longer *tubes*, *follicles*, or *sacs*, or into *branched* tubes or follicles, such as are seen in the stomach, intestines, or in the small mucous glands about the mouth; or this mode of extension may be carried so far as to lead to the development of the various large secreting and excreting *glands*, such as the salivary glands, the pancreas, the liver, and the kidneys, and even the lungs, which may be looked upon as glands, secreting carbonic acid. The mucous membranes are everywhere kept moist by a general secretion called *mucus* on their surface, of a viscid character, colourless, containing a few corpuscles, called mucus-corpuscles, and often detached epithelium cells, and composed of water, holding in solution or suspension a small quantity of an animal substance called *mucin*. The glandular parts of the membrane, of course, receive the various secretions formed by them. Lastly, the nerves of mucous membranes are in some cases special, as in the instance of the mouth and nose, where the membrane is not only sensitive to touch, but constitutes the part concerned in taste and smell.

The various modes in which, in the construction of glands, the secreting surfaces are increased in the body, within moderate spaces, are illustrated in the diagrammatic figures 65 to 67, and in the outline plans of actual glands given in figs. 68 to 70, all of which are much enlarged. They afford admirable instances of constructive design.

Fig. 65.—Supposing a simple secreting membrane, as a serous, synovial, or smooth mucous membrane, to be represented by the left-hand portion of this plan, in which the areolar vascular layer is indicated by a *red* or *double line*, the basement membrane by a *black line*, and the epithelial covering by a *dotted line*,—then, on the right hand, is shown the modes of increase by *projections*, either simple, plaited, or fringed. Examples of these are found in the simple or compound Haversian fringes of joints, p. 253, and in the ciliary processes in the eye, which are, in a sense, secreting parts.

Fig. 66.—Five modes of increase by *recessions*, which form *simple glands*. *a*, a tube, *tubular follicle* or *crypt*, like the simple gastric tubuli, diagram No. 6, fig. 7, p. 98, and the intestinal crypts of Lieberkuehn, fig. 12, p. 100; *b*, a sac or *saccular follicle*, like the Meibomian glands, diagram No. 8, fig. 25, p. 192, or like those of the large intestine, p. 101; *c*, a longer *coiled tube*, rolled up for packing in a small space, such as the special nasal glands, p. 174, the sweat-glands of the skin, diagram No. 8, fig. 2, p. 167, and the ceruminous glands of the ear, p. 177; *d*, a tube with loculi or depressions in it, called a *multilocular tube*, like the more complex gastric tubuli, p. 98; *e*, a sac with similar depressions at the bottom of it, or a *multilocular sac*, like the compound follicles of the tonsils, p. 90, or the gastric glands of the ostrich, fig. 68 of the present diagram. These two last forms conduct us to the *compound* forms of *glands*, illustrated in the next figure.

Fig. 67.—*f*, branched tubes, ending free or in loops, forming a *compound tubular gland*, represented by the kidney (see also fig. 69); *g*, a *compound vesicular*, or *racemose vesicular gland*, consisting of branched tubes, ending in clusters of short saccules or vesicles, represented by the mucous glands of the mouth,

p. 85, gullet, p. 91, duodenum, p. 100, larynx and trachea, p. 39; and as held together in larger masses, consisting of many such parts or lobules and lobes, forming the lacrymal, p. 193, salivary, p. 85, and pancreatic glands, p. 106. These are all called *conglomerate glands.* The liver, in which the finest ducts in the numerous lobules form a close network, p. 104, and therefore do not accord with any of the forms hitherto mentioned, may be called a conglomerate *reticular gland.*

Fig. 68.—Multilocular sac, or *gastric follicle,* from the secreting part of the stomach of the American ostrich.

Fig. 69.—Minute structure of the human *kidney;* consisting of bifurcated or dichotomous branched *tubuli,* ending in free or looped extremities, and having little rounded tufts of arteries, forming the glomeruli or *Malpighian corpuscles* (coloured red), connected with them. (See also p. 71.)

Fig. 70.—Small lobuli of the *parotid* gland, injected with quicksilver, to show its branched ducts and their vesicular terminations,—forming an example of the conglomerate or racemose vesicular gland. (See also p. 85.)

The forms of the different glands, however various, as just illustrated, have no necessary connection with the character of their secretions; for the gastric glands and the intestinal tubuli are similar in form, and so are the sudoriferous and the ceruminous glands, but their respective secretions are totally different; and so again the liver, which is recognizable in all the vertebrata, and in most of the invertebrata also, as pouring into the alimentary canal a *biliary fluid,* differs in form and structure, from a few simple tubuli in the worms and insects, to its highly complex characters in the higher animals and in man. The so-called basement membrane, which is not always to be demonstrated in glands, can hardly have any particular influence in different organs, for it is everywhere similar in structure. But the epithelial cells which rest upon it, differ more or less according to the gland examined, and are apparently the seat of a *vital selective* force, by which the products of the various secretions and excretions are separated from their common source, which is the fluid exuded from the vessels of the different glands. These epithelial cells, however, and the epidermic cells of the cuticle of the skin, which itself may be regarded as a hardened mucous membrane, have also evident mechanical uses, limiting, protective, and renovating, or cleansing. In certain situations, the epithelial cells exercise a special influence in the process of absorption, particularly in the absorption of the chyle in the small intestine, pp. 79, 100. But these points will be best explained as the different epithelia are described.

The Epithelial and Epidermic Tissues.

Figures 71 to 81.

These tissues are absolutely non-vascular, and consist of numerous microscopic *nucleated cells,* of various form and size, arranged in one or more layers, and held together, firmly or slightly, by a small quantity of moist or dry *intercellular matrix* or *blastema.* The nucleated cells, for the most part originally roundish, become either flat, *scaly*, or *squamous*, as it is called, as on the serous, synovial, and buccal mucous membranes, and on the skin, or they grow into little *columnar* particles, as in the stomach and intestines, or they remain *spheroidal* or *polyhedral*, as in the fine commencements or secreting parts of the ducts of glands, or they become *ciliated*, that is, provided with long moving appendages called *cilia*, as in the air-passages. The epithelium of any surface is hence called *squamous*, *columnar*, *spheroidal*, or *ciliated*, according to the form of its component microscopic cells. Though the different kinds of cells vary in size, the nuclei are more correspondent in this respect, ranging from $\frac{1}{4000}$th to $\frac{1}{6000}$th of an inch in diameter. From this circumstance, the relative sizes of the different cells represented in the following figures may be generally determined.

Fig. 71.—*Squamous* epithelial cells from the *peritoneum*. Those of other serous membranes, and of certain parts of the interior of the eye, and labyrinth of the ear, are like them; and those of synovial membranes also. The cells are flat, polygonal, and arranged compactly, and edge to edge, in a single layer. Hence this form is sometimes called a *tesselated* or *pavement* epithelium. The nuclei are always very distinct, and the rest of the cell is clear or scarcely granular.

Fig. 72.—*Squamous* epithelium, consisting of a single layer of oval or fusiform cells, from the inner surface of a *vein*.

Fig. 73.—Fusiform *squamous* epithelium cells, from the inner surface of an *artery*.

Similar kinds of epithelium line the cavities of the heart, and the interior of the thoracic duct and the larger lymphatics.

Fig. 74.—Hexagonal *tesselated pigment*-epithelium, from the internal surface of the *choroid coat* of the eye.

The pigment substance exists in this instance,—as well as in the epidermoid cells of the Negro's skin, in the ramified pigment cells of other tissues of the eye, in the pia mater of the spinal chord, and in the skins and deep tissues of frogs and other animals,—in the interior of the nucleated cells, in form of minute granules about $\frac{1}{20000}$th of an inch in diameter, which, curiously enough, do not appear *opaque black* when highly magnified, but transparent and nearly colourless. When set free in water, they exhibit, under the microscope, the *molecular* or *Brownian* movement peculiar to such minute particles of matter, of sufficiently light specific gravity to move about in that fluid. The dark black or brown colour is discharged by chlorine, showing its organic nature. The black substance found in the lungs of miners and of other persons is contained, not in nucleated cells, but in the interstices of the areolar tissue; it is partly carbonaceous, and its colour is not discharged by chlorine.

Fig. 75.—Polygonal *scaly* epithelium-cells, from the mucous membrane of the *mouth*. They are of large size, from $\frac{1}{800}$th to $\frac{1}{500}$th of an inch in diameter, and contain a bright nucleus.

Cells of this kind in the mouth, also near the entrance into the nose, in the fauces and œsophagus, and on the conjunctiva, form a *stratified epithelium*, that is, one composed of several layers, of which the lowermost cells are roundish, and the upper ones flat. They may be scraped off the surface, and are constantly being removed by desquamation, and renovated from below, like the epidermic scales of the skin. (See also fig. 80.)

Fig. 76.—Compressed polyhedral *glandular* epithelial cells from the lobules of the *liver*. (See p. 104.)

Cells of this kind are always soft and granular, and are called glandular from their occupying the secreting parts of the ducts of glands. In the gastric follicles (see diagram No. 6, fig. 8), they are oval or *spheroidal*, which latter is probably their primitive shape, even in the more solid lobules of the liver, where they eventually become compressed or polyhedral. The peculiar ingredients of the different secretions are usually formed in these cells, which in their growth are supposed to be the chief agents in the elaboration or separation of these ingredients from the fluid plasma of the blood. Towards the outlets of the ducts of glands, the epithelium gradually changes in its character to that of the contiguous mucous membrane, and is called *transitional*.

Fig. 77.—Flat, dry, and horny *scales*, from the surface of the *epidermis* or *cuticle*, the nuclei indistinct or obliterated. (See also diagram No. 8, fig. 4, p. 160.)

Fig. 78.—*Columnar epithelium* from the *small intestine*. *a*, sectional plan across a part of one of the intestinal villi (see also diagram No. 5, fig. 5, p. 77), showing the elongated columnar epithelial cells, fixed perpendicularly on the surface of the villus, by their somewhat narrower ends; *b*, more highly magnified view of the free ends of a few cells, which have a mosaic-work appearance, and show their nucleus plainly; *c*, side-view of a single columnar epithelial nucleated cell. As a curious instance of nice mechanical adaptation in the body, even in such minute things, it may be mentioned that the nuclei of adjacent cells grow at different levels, so that the cells may fit compactly.

A columnar epithelium is found all over the stomach and throughout the whole intestinal canal. From the peculiar arrangement of its particles, which are moreover but slightly held together by a soft intercellular substance, it is adapted to allow a general absorption, through their interstices, of the watery and soluble parts of the food, into the returning capillary current. But the cells themselves are supposed to take a special share in the lacteal absorption of the chyle, or at least of its fatty portion; for during digestion the columnar epithelium-cells on the villi are seen to be filled with fluid fat, which is believed to enter them from the intestines, and then to be poured by them into the commencing lacteals (see also pp. 77, 79, 100). Some very fine longitudinal striæ, seen at the thicker free ends of the cells, have been conceived to be pores or passages through which the fat may enter.

A columnar epithelium is also found in the gall-bladder, where the bile is undoubtedly inspissated by absorption of its more fluid parts; and also in the larger ducts of glands, where it becomes transitional, and so passes into the glandular forms.

Fig. 79.—*Columnar ciliated* epithelium, from the mucous membrane of the smallest *bronchial tubes.* *a*, a few such cells set, in a single layer, upon the subjacent tissue, and having on their free ends the little hair-like processes called, from their likeness to the eyelashes, *cilia;* *b*, a single cell further magnified.

Fig. 80.—Plan of a section of the *stratified epithelium* of the conjunctival mucous membrane of the calf, showing its many layers of nucleated cells, and the mode in which these are developed and metamorphosed. The deepest cells, newly formed, *d*, are smallest and spheroidal; then they become ovoid and larger, as at *c*, and also more or less compressed or polyhedral; still higher, at *b*, as they advance towards the surface, they become flattened out, polygonal, and either meet or overlap at their edges; lastly, at the surface, as at *a*, they assume the form of minute thin scales, in which the nucleus has become indistinct. In this state they are continually thrown off, new ones being developed from below.

Fig. 81.—*Columnar ciliated* epithelium, from the inner surface of the *trachea.* This, as shown by the layers of nucleated cells, is an example of a stratified epithelium, the upper layer being columnar and ciliated. Besides a small mass of cells, three detached cells, two in an early condition and one fully developed, are shown. The cilia upon it would measure about $\frac{1}{3000}$th of an inch in length.

A columnar ciliated epithelium, of one or several layers, is found in the nasal cavities and sinuses, in the upper half of the pharynx, in the Eustachian tube, but not in the tympanum; in the nasal duct as far as the lacrymal sac, and in the larynx, trachea, bronchi, and finest air-tubes, but not in the air-cells. A ciliated epithelium is also found lining the ventricles of the brain, but it is flattish or tabular, and not columnar. In the vertebrata generally, a ciliated epithelium exists in corresponding places. A spheroidal ciliated epithelium is found in the frog's mouth. In all the aquatic invertebrata, cilia are found, either on the gills or respiratory organs, as in shell-fish, or on the tentacula around the mouth, as in polypes, or upon parts of the body, as in infusorial animalcules, or over the entire surface, as in most aquatic invertebrate ova.

In all cases, the cilia are soft, flexible, homogeneous little organs, the chemical composition of which has not been determined. During life, and in the case of the warm-blooded animals for a short time after death, and in that of cold-blooded animals for a very long time after death,—they perform a remarkable waving or lashing movement to and fro, regular, progressive, and in a definite direction. At first, as examined under the microscope, this movement is too rapid to be clearly analyzed; but, when slower, it is seen to produce an undulating motion like that of a field of waving corn, the effect of which is to hurry forward in a given direction any fine particles in the fluid in which they are examined. The cause of this movement, or *ciliary motion* as it is called, is not known; but it is probably dependent on some modification of the vital contractility characteristic of muscular tissue. It is not, at least in the higher animals, influenced through the muscular system.

The uses of the ciliary motion are obvious. It moves the aquatic ova about in the water till they meet with a fit place for their development; it is the locomotive force of the animalcules; it helps to bring small particles or objects of food to the mouths of the polypes; it changes incessantly the stratum of water in contact with the respiratory organs of the mussel, oyster, and other shell-fish; and in the vertebrate animals it serves to propel the mucus of the surface of the air-tubes slowly upwards towards the glottis, to distribute the nasal mucus charged with odorous matters over the surfaces of the olfactory region, and to aid in diffusing a uniform moisture over the sides of the ventricles of the brain.

The *defensive* office of the epithelial tissue, which belongs more or less to each of its varieties, is exercised specially by the squamous kind; slightly in parts subjected to mutual contact, pressure, and friction, as in the single layers covering the serous and synovial membranes; more markedly in parts with which foreign bodies are likely to come in contact, as in the stratified layers covering the conjunctiva, the entrance of the nostrils and ears, the mouth, the fauces, the lower half of the pharynx, and the gullet; and more evidently still on the many-layered thick and dry epidermic form of this tissue on the general surface of the body. The *cleansing* function of the epithelial and epidermic tissues, owing to the constant renovation of its cells, is best exemplified in the gastro-pulmonary mucous membranes, especially in those with stratified epithelia, and in the skin. The protective influence of the ciliated epithelium is of a special kind, keeping the parts covered by it, as the nose and upper half of the pharynx, the larynx, and rest of the air-passages, continually moist, in spite of the drying effect of the air upon them.

The general *absorptive* office through epithelial tissue is very rapid in the case of the thin single layers of the serous membranes, and also in the columnar kinds; but it is through the latter that absorption takes place specially, as already explained in regard to the fluid parts of the food and the chyle.

The *secreting* power of the simple squamous kinds of epithelium belonging to the serous and synovial membranes, is limited to the separation of an albuminous fluid, so like to the liquor sanguinis, or to the fluid part of the blood, that it may be regarded as an exudation merely. The general surface of all the mucous membranes pours out a fluid mucus, a little more elaborated, different from the fluids of the blood, and consisting apparently of a thinner condition of the intercellular blastema which holds the epithelial cells together. It is, however, in the glandular epithelium that the highest development of secreting power resides. In the case of the secreting glands, the peculiar products of or secretions from which are intended to be used again in the economy, the *secretions* themselves may be regarded as consisting essentially of the glandular epithelial cells, fully developed, charged with their special contents, and then burst, dissolved, or suspended in a certain amount of saline fluid. Secretion in such a case consists in the growth and casting off of nucleated cells, in the interior of which the characteristic constituents of the secreted fluid are elaborated from the plasma of the blood. This is the case with the gastric juice, the bile, and the milk. Such a process is evidently analogous to the nutrition of the other epithelial tissues and the epidermis, whose particles are also being constantly thrown off. Nutrition has indeed been regarded, even in the case of all the tissues, as a similar process, and has been called *nutritive secretion;* it is also carried on by the intervention of nucleated cells, only these are not cast off.

In the case of *excretions*, which are not to be used in the economy, but to be cast out of it, such as the sweat, and the urinary excretion, and, it may be added, the carbonic acid from the lungs, the glandular epithelium-cells concerned probably do not *elaborate* the substances to be passed out of the system, but merely *attract* them, ready formed, from the neighbouring blood, and liberate them again into the excretory ducts.

The characteristic constituents of the true secretions do not exist in the blood, and are never formed except by their special gland; whereas the constituents of the excretions pre-exist in the blood, and may escape, as in the case of disease of their ordinary excreting organ, by other channels.

In concluding this account of the microscopic structure of the tissues of the human body, it has, finally, to be remarked that the building-up of its various parts and organs by the aggregation of such countless hosts of elementary constituents, traversed more or less nearly by multitudes of capillary vessels conveying a common nutritive fluid, wonderfully facilitates the pre-ordained, simultaneous, and harmonious evolution of all those parts in the processes of *growth*, from the embryonic to the mature state, and also the subsequent processes necessary to their *nutrition*. For, as in all vital action, and as the result of such action, the various tissues *waste*, molecule by molecule of their component cells or blastema, or of their simple or compound fibres, and as the products of this detailed wasting or molecular *destruction* are carried off by the returning blood-currents, so the incoming current supplies materials, which are thus enabled, by a reversed interstitial process, to restore, by a miracle of molecular *deposition*, that exhausted frame which is so "fearfully and wonderfully made." It is the occurrence of these changes in the great corporeal aggregate, or body, which constitutes *Life*, whilst their final cessation is corporeal *Death*, when "the dust shall return to the earth as it was, and the spirit shall return to God who gave it."

FINIS.

LONDON: W. H. HODGE, STEAM PRINTER, 9, RATHBONE PLACE, OXFORD STREET, W

Mr. ALFRED TARRANT has the honour to announce that he is now publishing the important Series

PHYSIOLOGICAL DIAGRAMS,

Prepared originally for the Department of Science and Art, under the direction of JOHN MARSHALL, Esq., F.R.S., F.R.C.S., Professor of Surgery, University College, and Surgeon to University College Hospital,

The Series is complete in NINE DIAGRAMS, Life Size, each printed in one piece, without a join, on paper 7 feet by 3 feet 9 inches, coloured in fac-simile of original Drawings.

No. 1.—THE SKELETON AND LIGAMENTS.
No. 2.—THE MUSCLES AND JOINTS, WITH ANIMAL MECHANICS.
No. 3.—THE VISCERA IN POSITION—THE STRUCTURE OF THE LUNGS.
No. 4.—THE HEART AND PRINCIPAL BLOOD-VESSELS.
No. 5.—THE LYMPHATICS OR ABSORBENTS.
No. 6.—THE DIGESTIVE ORGANS.
No. 7.—THE BRAIN AND NERVES.
No. 8.—THE ORGANS OF SENSE AND VOICE.
No. 9.—THE TEXTURES—MICROSCOPIC STRUCTURE.

Price of each Diagram, 12s. 6d.; or, Mounted on Canvas, with Roller, and Varnished, 21s.

OBJECT OF THE PUBLICATION.

IT has long been urged by enlightened men, at different times, that every educated person should know something of the structure and uses of the several parts of his own frame. Able and luminous works, calculated to convey such knowledge in a simple and interesting style, have emanated from the pens of distinguished authors, and amongst the adult population of the present day there are many who have availed themselves of that useful and agreeable source of self-instruction and improvement. But only recently has it been felt and expressed by the advocates for enlarged plans of general education, that no scheme of instruction for our youth can meet the just requirements of the future inheritors of our social position and responsibilities as a great and civilized community, which does not include some explanation of the general plan and fundamental laws of the animal and especially of the human economy. In many public and private schools, attempts to impart this information to youthful minds have been followed by marked success. Educational *books* intended for pupils exist in considerable numbers and of various merit; but teachers actually engaged in communicating a general knowledge of anatomy and physiology by class-lectures and demonstrations, feel and acknowledge a serious defect in the educational means now at their disposal, for the want of good *diagrams* and *models*, which shall at once be sufficiently *large*, *accurate*, *intelligible*, and *cheap*.

This series of Diagrams, illustrating the structure of the human frame, is issued in some measure to supply this deficiency.

Original drawings, prepared for the Department of Science and Art, have been made from Nature and existing figures by Mr. Cuthbert, under the superintendence of Professor Marshall. These drawings Mr. Erxleben has been employed to transfer to the zinc. In points of clearness and accuracy, it is hoped that they leave little or nothing to be desired; and it is believed that their artistic merit will tend to dissipate the less agreeable associations commonly connected with anatomical objects. Their great size not only renders them fit for the walls of lecture-rooms and schools, but gives them interest as the largest works yet executed in zincograpy. The plates, paper, and press have all been specially made for the occasion.

The expenses attending the production of these diagrams have therefore been great, but due regard being had to the absolute necessity of meeting not merely the *wants* but the *means* of almost the humblest schools, their price is fixed at an unprecedentedly low rate.

Though expressly designed for the wider purpose of general education, supplying an acknowledged necessity of modern teaching, these diagrams will be found not inapplicable to the requirements of professed Medical Schools, affording as they do a correct preliminary view of the various systems and organs in the human body.

To Lecturers at Literary, Scientific, and Mechanics' Institutes, or to the Committees of such Societies, the entire series would be peculiarly useful, and finally to both teachers and students of Artistic Anatomy, a selection suspended on the walls of the lecture-room or studio, could not fail to assist in imparting or securing, through the medium of the eye, that familiar acquaintance with the principal points in the osseous and muscular systems, which is indispensable to a just appreciation of the rich complexity of the human form.

LONDON:
ALFRED TARRANT, 11, Searle Street, Lincoln's-Inn Fields.
AND ALL BOOKSELLERS.